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SCIENCE IN WAR AND PEACE

Presidential Address by

SIR HENRY DALE, O.M., G.B.E., F.R.S.

and

OTHER ADDRESSES

by

PRESIDENTS OF SECTIONS

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THE ADVANCEMENT OF SCIENCE

VOL. IV, No. 15 SEPTEMBER, 1947

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THE PRESIDENTIAL ADDRESS

SCIENCE IN WAR AND PEACE

BY

SIR HENRY DALE, O.M., G.B.E., F.R.S.

THE British Association begins to-night its first normal meeting since 1938. As many of you will remember, the Association assembled here on August 30, 1939, for a meeting which in many directions gave promise of a success as great as that of any in its history. The only factor of doubt in the prospect was the threat of approaching war. Sir Albert Seward delivered his address from the Chair on August 30, and the City and Royal Burgh of Dundee, led, my Lord Provost, by your distinguished predecessor of that year, Sir John Phin, received the Association here, in the Caird Hall, on the evening of September 1. Thereafter the tension rapidly increased to breaking-point, and, fearing an interruption of all the means of transport, the Members dispersed to their homes. Thus the Meeting of 1939 dissolved, with only a small part of its purpose achieved.

On behalf of my Fellow Officers and myself, of the Council of the British Association and of all its Members now assembled here, I desire to express to you, my Lord Provost, to the local Secretaries and Committees and to all who have come to their aid, to the University College and to all the citizens of this Royal Burgh, our grateful and admiring sense of the splendid act of generosity, by which, in spite of all difficulties which the restrictions and austerity of the time impose, you have invited the Association here again, at the earliest possible opportunity. I can assure you of the fervent wish and intention of everybody connected with the British Association, that our Meeting should, on this occasion, be as complete and successful in every way as you, our friends and generous hosts in Dundee could desire, and as you have so abundantly deserved.

During the war the annual meetings of the Association as a whole were perforce suspended, but its function of providing a forum for discussion of the interests of science, and of its proper place in the life of the community, of the nation and of the world, was not allowed to fall wholly into abeyance. Sir Richard Gregory had been elected President for 1940, and in that and each of the five following years he presided over a meeting in London of the Division of the Association which deals with the Social and International Relations of Science. Finally, last year, there was a meeting for one day, also in London, of the Association as a whole, at which Sir Richard Gregory was able, at length, to deliver the inspiring Address from the Chair, for which the Association had been obliged to wait through all the years of the war. We owe to him, and to the Division which, under his leadership, has provided thus annually a rallying-point for scientific opinions and interests, a lasting debt of gratitude.

The Officers and Council of the Association have naturally wished that this meeting should take special note of the emergence of science, in Britain as in other countries, from its abnormal concern with war, and its return to the service of peace. To rally and to give direction to the thoughts of the Members and of the Sectional Officers in this general sense, the phrase 'Swords into Ploughshares' was suggested, and adopted by the Council, as a motto for the meeting. Even in its most obvious meaning, the metaphor will find abundant application in the coming week of discussions. Let me choose a few, almost at random, for mention now.

How many decades of research do you suppose, undertaken in response to no stimulus stronger than the desire to add to the resources of peace, would have been required for those developments of radiolocation and radar, which were achieved in a few years under the imminent threat and the realised peril of war? It is certain that the scientific activities of peace had never witnessed anything like the intimate collaboration of British and American physicists and engineers, which finally played so important a part in giving full effect to this triumph of science in the service of war, with its value, so immediate, for the safety of transport in peace.

Aeronautical science, having received a

great stimulus in the earlier world war, and having undergone a steady development in the intervening years, sprang again into a phase of headlong progress under the threat and the experience of the new war. And now we wait to see what will be the effects, on speed and safety in peaceful transport, of gas-turbine engines and jet propulsion, of stratosphere flight in pressure cabins, and of the fundamental changes in aircraft design, which are all still under rapid development.

We cannot doubt that the survey by Sir Howard Florey and his team, which led them, in 1939, ten years after its discovery by Sir Alexander Fleming, to take penicillin down from the shelf of sound but unexploited observation for the new study which brought it so rapidly into practical use, owed some of its stimulus to the gathering menace of war, with the prospect of infected wounds and diseases of campaign, demanding more and better means of dealing directly with bacterial infections. And we may certainly assume that the lavish character of the industrial research and enterprise, which then so quickly overcame the difficulties of manufacturing penicillin on a large scale, was chiefly due to recognition of the part which it would play in the conduct of the war. And this industrial production, again, made penicillin, and then several penicillins, more rapidly available for the purely scientific investigation of their chemistry. Here, again, the conditions of peace have never produced such a remarkable co-operative effort of research as that in which teams of some of the leading chemists of this country and of the United States pooled their results, solved the difficult structural problem with what, by normal standards, would have been an astonishing rapidity, and even, in the case of one of the penicillins, confirmed by synthesis the structure to which the less direct evidence had pointed.

Since the 17th century Cinchona and its chief alkaloid, quinine, had continued to provide the standard medicinal treatment for malaria, although, between the two world wars, the research enterprise of German industry had produced two new artificial remedies. One of these, indeed, known as atebrine, and later, in this country, as mepacrine, was understood to be comparable in action to quinine, though there had been no sufficient inducement or opportunity for its complete trial as a substitute. It was fortunate, then, that, as a military precaution, the effective manufacture of mepacrine had been undertaken in this country, and then in the United States, before Japan seized, in the East Indies, the source of most of the world's supply of quinine. Without mepacrine to replace it, indeed, this loss of quinine occurring just as the war was extending so rapidly into malaria-infested regions of the Tropics, might have involved a military disaster and a human tragedy of the first magnitude. Under the continued stimulus of war's demand, again, a new campaign of chemotherapeutic research was opened in both Britain and the United States, to seek yet better remedies than quinine or mepacrine. Again there was a co-operative exchange of information and materials between the workers in both countries, and the investigation was conducted on such a scale and with such organisation of effort as had never been contemplated in peace. In a surprisingly short time came reports of new lines of development showing great promise ; and a British one of these has culminated, so far, in the discovery of paludrine, a synthetic antimalarial substance of a new type, more effective, and at the same time much freer from harmful accessory activity than quinine, or mepacrine, or any other of its predecessors.

The needs of war, again, soon presented to engineering, on the one hand, and to physiology and experimental psychology on the other, a group of practical problems arising from the unnatural conditions of physical and mental stress to which men were exposed in the constantly developing machines of modern warfare—airplanes, tanks, submarines and the rest—as well as from the extremes of climate and the deprivations to which they were subjected by military necessity or accident. And the researches which were framed and conducted, in response to these varying demands, have produced a great volume of new knowledge concerning a variety of conditions which favour or hinder the different activities of man's body and mind, and their resistance to the influence of fatigue. War has thus enforced a lesson which surely should not be forgotten in peace, that machinery was made for man and not man for machinery.

Not all the uses of war-time discoveries in peace will depend on applications so direct and obvious. There are examples already, and it is most likely that more will appear, of inventions made with no purposes but those of war, which have found peaceful use in directions entirely unforeseen. Let me select one such case for mention. An artificial chemical substance, di-isopropylfluorophosphonate, now commonly known as D.F.P., was first made and studied in this country, as an active member of a poisonous series, known to be under trial in Germany as potential weapons of chemical warfare. The actions of D.F.P., some of them unpleasant enough, were found by workers in this country, whose results were later confirmed by colleagues in the United States,

to be due to its power of annulling the action of cholinesterase—an enzyme, widely distributed in the animal body, and playing an important rôle in relation to the transmission of a number of nervous effects. D.F.P. was never used, in fact, as a chemical weapon; but the action which might have led to such employment has already made it, not only a most interesting and valuable tool of physiological research, but also, according to recent news from the United States, an invaluable remedy, when suitably administered, for the dangerous paralysis of the intestine which may follow an operation. So the wheel has come full circle, and the sword, forged as a lethal weapon, finds use, not only as a ploughshare of peaceful research, but even as a shield for threatened lives. This scientific by-product, of war as now planned between the world's most advanced civilisations, thus seems likely to take its place with a number of poisons traditionally used by savage peoples for warfare, hunting, or murderous ordeal, which have already found applications in our modern medicine.

The sectional meetings during the week will certainly have under discussion many more of such direct applications and extensions of discoveries and inventions made in war, to the ordinary needs and purposes of peace. These will constitute, however, only a part, and very likely not the most important part of the incidental and compensating gains of science itself, and of mankind through science, from this participation in the researches required by war. Scientific research may expect to obtain, from inventions thus made for special and quite unrelated purposes, new tools and facilities for the general advancement of natural knowledge over wide ranges. The development of rockets as weapons of extreme range, for example, may provide means for obtaining data of physical conditions, at altitudes from the earth's surface previously far beyond the reach of scientific exploration; and the great advances made in aerial photography will certainly find application for purely scientific surveys of various kinds, over land and sea. And, apart from many and great additions of this kind, to the physical and technical resources available to research, there will be lessons to be learned from war's experience of the methods of planning and organising research, of the recruitment of special research teams, of the value, for the rapid attainment of a particular objective, of co-operation on a national and, as in cases which I have quoted, on an international scale. All such experiences in war will have left lessons which may have value in peace, to science in the pursuit of its normal objectives, and to the world at large in a new understanding of what science can be expected to do, and of the ways in which its aid can be invoked.

It may be of at least equal importance that we and the world should, with all rapidity and thoroughness, forget other lessons, which ought to be discarded. It is hardly to be doubted that, to many scientists, the war brought opportunities for research under conditions which were, in various ways, and in spite of the strain and anxiety of the time, more immediately attractive than any that they had previously encountered. Comradeship, effective even across some national boundaries, in work for a great cause, without thought of personal credit or recognition; an escape, perhaps, from indecision concerning the scientific worth or soundness of a line of personally chosen research, and from anxiety as to material resources for its pursuit, into a world of authority and planning, of problems posed by actual emergencies, of practical issues and tangible results, and of facilities without restriction; and a sense withal of high duty performed for the future of his country and of the world, by the use of a man's own special knowledge and skill, and not always without danger—duty as clear and unquestionable as others could only discharge by a sacrifice of all their normal instincts and interests and, for many, of life itself—all these conditions of scientific war service may have given to many a man a different kind of satisfaction, from any which had come to him from the normal experience of a scientist in peace. Some there must be, to whom this conscription of science for war gave even their first opportunity of testing the joys of research, and of putting their own natural equipment for it to the test of performance. And I suggest that there may be danger to science from a tendency to transfer too easily and completely, to the activities of peace, the attitude to research and the traditions of its conduct which have been acquired during six years of such war experience.

I am not, of course, thinking just now of the perversion of science which war research involves through its particular business with the means of slaughter and destruction. For the moment I am concerned with the fact that the response to war's demands has led the majority of scientists of this country to devote nearly the whole of their thoughts and efforts, during six years or more, to practical problems presented to them for rapid solution. There must, indeed, be many younger men who have had little experience of other kinds of research than that which has been thus directed and even restricted to near and practical objectives and carried out under a pressure of urgency. From Government

organisations and industry, awakened by war's experience to a fuller awareness of what science can do for them under such conditions, it is not likely that encouragement will be lacking for a continuation of similar activities into peace. Have not I myself been bringing to your notice lines of research, which proved fruitful of practical result for the purposes of war, and should be continued and developed now, with a new orientation, to serve those proper to peace? I must make it clear, then, that it is far from my intention to suggest a predominance, in the programmes now to be shaped for science, of research enterprises such as those of war and of the methods by which they have been conducted.

Does anyone doubt that, to enable science now to render its best service to mankind, we need to take a long-range view and to give our first care to the extension of fundamental knowledge, unconstrained by aim at any practical objective? I am not concerned to advocate, or to defend a philosophy postulating the advancement of pure knowledge on the one hand, or the material betterment of man's lot in the world on the other, as the ultimate motive of the scientific effort. I believe that it would be admitted, by partisans of either doctrine, that research which seeks only to advance pure knowledge commonly leads in the end, to the widest practical developments; and that examples are plentiful of practical researches, conducted under conditions which leave full freedom to follow side issues, opening the way to great fundamental advances. The concentration, however, of practically the whole of a rapidly growing scientific effort on practical applications and developments, such as the war has witnessed, might find instructive analogy in a rapid extension by a commercial undertaking of its trading enterprise, without care to conserve and to expand its working capital; or in a reckless cropping of land, without care to nourish the soil. In theory I think that this is generally recognised, and I am far from suggesting that any of the different authorities which now provide material support for science in peace will hesitate to give generous encouragement to fundamental researches. My fear is rather that we scientists ourselves may find it difficult to shake off quickly the spendthrift habit in research, the policy of trading for quick returns, which six years of war experience may so easily have fostered, and may even have made congenial to many of us.

I venture, further, to voice a hope that men with the rare, creative ability that science needs now for the resumption of its normal progress in peace, whose influence and example are needed in the schools for the inspiration of those who will follow, will not too readily assume, or too easily be persuaded, that their best service to science can still be rendered by planning and organising, or by bringing scientific ideas to bear upon policy. I believe that, under conditions now to be faced, the building up of our scientific capital of fundamental knowledge by those who have the creative gift, should have a prior claim over its practical exploitation and over any cultivation of its political influence.

There are many, I think, who will be remembering with me the mood which prevailed among men of science when the first world war ended in 1918; how we looked forward then with eager hope and confidence, ready to write off the losses and delays which those four years of war might have inflicted on science, and determined to conserve for it all that could be counted as gain. The rôle of science in that war had, indeed, been relatively small. For the general body of scientists it had begun on a basis of opportunist intervention or response to special appeal, to deal with emergencies as these arose, the country's scientific reserves being called upon tardily and never completely enrolled. And, when victory came in 1918, the men of science, with few exceptions, were able quickly to escape from war's abnormal duties and commitments, and to return rejoicing to the free air and the wide horizons of science, as they had known it earlier in peace. Lessons had been learned then, as now; the Government and public opinion had gained a new conception of the support of scientific research as a national investment; but thoughts of war, and of its claims on science, receded rapidly then into the background. And although what was to have been a permanent peace proved, in the event, to be less than two decades of an uneasy armistice, with the shadow of another war then rapidly encroaching, what a wonderful new flowering of science was witnessed in that short interval!

Think of the speed and completeness with which our ideas of the universe of matter, of atoms and of the ultimate, subatomic particles, of elements and their mutability, were then being recast; of the transformation, as rapid and impressive, of conceptions of the life process and its physico-chemical background, by the advances then being made in organic and physical chemistry, with biochemistry in ever more intimate alliance with them; of the new worlds of knowledge and ideas which were then being opened by the linking of genetics and nuclear cytology, giving a physical basis to the complexities of heredity; or of the first systematic study of the properties of ultramicroscopic viruses, combining, in a manner still mysterious, the

characters of matter in macromolecular solution with those of the smallest living and self-propagating organisms. From all these, and from fundamental advances of comparable rapidity and significance in almost all fields of scientific activity, rich harvests of new development and extension were continuously being reaped, by medicine, agriculture, industry, and all the branches of applied science. Never, surely, in all previous history, had science surged forward with such impetus, as in that interval of years when, in spite of recurrent economic and international crises, a lasting peace seemed still not beyond hope, and a golden age, for a world entering the scientific era of its history, a not impossible aspiration. And, for science itself, one of the points of brightest hope and encouragement was to be found in the steady rebuilding in that interval, in spite of initial obstacles and discouragements, of a true world community of science.

We know how tragically that interval of optimism and of free progress in science, so rapid and so various, came to an end. We cannot expect, and there is little yet to encourage, a quick revival of that earlier mood. We are faced now by the contrast between the parts played by science in the two world wars. In that from which we recently emerged, science, no longer a mere accessory, has moved right into the centre of the picture; and, by a process of which we may, perhaps, find the tentative beginnings in 1915 with the first use of chemical warfare as a weapon of mass slaughter and disablement, the belligerent use of science has undergone a rapid transformation, turning it into a weapon and a combatant in itself, released from afar for the undiscriminating infliction of death and destruction, at rapidly growing ranges and on an ever-increasing scale. The atomic bombs on Hiroshima and Nagasaki represent, of course, an immediately visible peak of this development; but nobody can suppose them to be the ultimate climax of disastrous achievement, if the nations should persist in the desperate project of using further advances in this, or in any other department of science, to prepare in secret, each to excel or to anticipate others in perfecting the means of annihilation. Does the world need yet to be warned as to the end of such a policy? If so we scientists must continue, against any reluctance, to proclaim the danger, and therewith our hatred of the perversion of science which it involves.

Meanwhile we have our own problem of the effect of such a position on the prospect of science itself. For a devotion so complete to the service of war as that which we gave in these recent years has involved many of us in obligations of secrecy entirely new to our experience; and there are important sections of scientific activity which have not yet been able to escape from these trammels. The project concerned with the release of atomic energy, with all the side issues into new lines of fundamental and beneficent progress which that gigantic war enterprise may yet make available, provides the most conspicuous case. It might, indeed, be regarded as presenting an extreme example, of the way in which science in peace may inherit opportunities from developments for which war alone could have set the scale and provided the momentum, and also, alas, of the threat to the freedom of science which may be entailed by the same inheritance. Though the scientific basis for its prediction was available in 1939, before the new war broke out, nothing but war, and the need to anticipate a danger of such magnitude in war, could have brought about an effort on the scale needed to convert the release of atomic energy by a chain-reaction from theory to practical reality in a few years. The world might have had to wait for many decades of unbroken peace to reach a point of such possibilities, for new departures and rapid advances in a whole range of the fundamental sciences and of their applications in medicine and engineering alike. War immensely accelerated the arrival of this opportunity for science, but, in doing so, compromised the peaceful enjoyment of it by the hideous threat of its further abuse in war. Science, then, finds itself facing a situation in which hope and frustration contend; the need to make the world safe, and the delay of agreement on the means of doing so, clog wheels of science which should even now be turning freely for the enrichment of knowledge and of human life.

How then are we men of science to deal with such a situation? With unquestioning loyalty to all our obligations; that first and foremost; but then also, I would urge, with a resolute watchfulness against any encroachment, on activities proper to peace, of a secrecy which we accepted as an abnormal condition in war, and with a determined effort to accelerate the liberation of science from all such entanglements. In the universities in particular, as I have elsewhere advocated, I hope that we shall be able to ensure that the scientists of the near future will grow up as we their predecessors did, in an atmosphere of scientific freedom, so that they may be ready to accept, in their turn, the duty of standing, at need, in the defence of science in its full integrity. And I hope that we can keep as the constant aim of our endeavour, in spite of all present difficulties and causes of discouragement, the revival of an intimate brotherhood of the men

of science of all nations, working together in full confidence, once more as a world community.

The purposes ascribed to the British Association at its foundation in 1831, and, after 97 years of experience, introduced without change into the Royal Charter in 1928, were as follows :—

> ' To give a stronger impulse and a more systematic direction to scientific enquiry ; to promote the intercourse of those who cultivate Science in different parts of the British Empire with one another and with foreign philosophers ; and to obtain more general attention for the objects of Science and the removal of any disadvantages of a public kind which impede its progress.'

As a definition I do not think that we could improve upon that to-day, and we need only consider its application to the conditions which face Science and the Association now. We rejoice that, in spite of our war legacy of austerities, so many fellow scientists from other lands have allowed us to welcome them to our scientific fellowship on this occasion of our full re-emergence, and have given us the opportunity to show them that this British Association is still concerned for the advancement of a Science which belongs to all the world. And, with regard to the last clause of the definition, it seems to me that never, in its long history, was there a more urgent call than to-day for a faithful discharge by the Association of its duties of interpreting the purposes and the true meaning of Science to a wider public, of advancing the interests of Science and of defending its freedom from extraneous pressure or adverse influence.

With regard to the Association's function as interpreter, we shall find many to-day who, through genuine misunderstanding and confusion of thought, are looking askance at Science, imputing to Science itself the danger, with which a misuse of its gifts to mankind still threatens the future of the world, and imagining Science to be concerned, in any case, with material issues alone, and as playing, therefore, no part, or even a negative one, in the spiritual and cultural equipment of mankind. We can hardly be surprised at such misunderstanding, when we remember the completeness with which Science has been absorbed, for all these years, in the technical aspects of war ; but it is the more our duty to expose and to counteract it wherever we may meet it. Science, we must let it be known, pursuing its own task, seeking such a progressive revelation of the truth concerning material nature as its methods can achieve, fearing only error and prejudice in observation or inference, regarding authority, tradition, or permanence in scientific doctrine as a danger—Science thus fulfilling its mission in freedom can make its own special contribution to the cultural and moral equipment of mankind, which the world, now moving fast into the scientific era of its civilisation, cannot afford to lose or to discredit. Some of you doubtless have read that, in an address which the Master of the Rolls, Lord Greene, gave recently to the Classical Association, he included Science as a proper constituent of a course of humane study, which he was advocating for schools. I think that we should give an enthusiastic endorsement to that noble plea.

And then there is our duty of defending the right of Science to pursue unhindered its own task for mankind, within its own sphere. It needs but little imagination, I think, at a meeting such as this, to hear echoes from afar of historic encounters, in which, many decades ago, stalwarts for scientific truth in this Association stood firm in their resistance to attempts made on the authority of ancient traditions and orthodoxies to set limits to the freedom of scientific enquiry. Those battles were won and even their memory is fading; but I believe that now, in a torn and groping world, we of this Association may need still to be on guard, lest some new and extraneous philosophy or political system, invoking, perhaps, the authority of Science to bolster its pretensions, may seek again to limit and to compromise, with a new orthodoxy, the freedom of Science to seek and to proclaim such truth as it can discover, not as an expedient, but for its own beauty and for its beneficent promise to mankind.

SECTION A.—MATHEMATICS AND PHYSICS

EARTH, STARS AND RADIO

ADDRESS BY

SIR EDWARD APPLETON, G.B.E., K.C.B., D.Sc., LL.D., F.R.S.

PRESIDENT OF THE SECTION

DURING the year 1947 we are celebrating in this country two important Jubilees, one technological, and the other scientific. Both of them are relevant to the subject of this discourse. It was in 1897, fifty years ago, that Marconi, the young Italian inventor, gave a decisive demonstration of his system of 'telegraphy without wires' to Sir William Preece, who was then the Engineer-in-Chief of the British Post Office. In the same year the first permanent wireless link was installed between the Needles, in the Isle of Wight, and Bournemouth, the communication distance being 14½ miles. It was also in 1897, that the Cambridge Cavendish Professor of Experimental Physics, Professor J. J. Thomson, later Sir Joseph Thomson, made the first public announcement, at an evening discourse at the Royal Institution, of the existence of the electron as an independent entity. As we shall see, the technological development of radio from those early beginnings has had important scientific consequences. As we shall also see, the scientific discovery of the electron, although important in the first instance because of its direct bearing on the theory of the atom, has had profound technological consequences. Indeed I do not think it is possible to cite better examples of the mutual influence of fundamental science and technology than the developments which have sprung from these two great events of fifty years ago.

It was on February 2, 1896, that Signor Guglielmo Marconi arrived in England and was welcomed by Mr. W. H. Preece, the Engineer-in-Chief of the British Post Office. Mr. P. R. Mullis, a member of Preece's staff at the time, has given an account of this first meeting as follows :—

'One morning in the year 1896 Mr. Probert, the Electric Light Superintendent, brought into Mr. Preece's room a young dark looking foreigner, who was introduced as Signor Guglielmo Marconi. Signor Marconi had with him two large leather bags the contents of which were placed on the table, and seemed to consist of a number of brass knobs fitted to rods, a large spark coil and some odd terminals, but most fascinating of all, a rather large-sized tubular bottle from which extruded two rods terminating inside the bottle on two bright discs, very close together, and between which could be seen some bright filings or metal particles.

'After one or two preliminary adjustments to the connections and brass balls by Signor Marconi, the key was depressed and immediately the bell on the adjacent table commenced to ring, and continued to ring. Marconi then went over to the glass tube and gave it a few sharp taps, when the bell ceased to ring. Again the key was depressed and again the bell rang and continued to do so until the tube was shaken.

'I knew by the Chief's quiet manner and smile that something unusual had been effected.'

From that first meeting onwards, we can recall with much pride, W. H. Preece gave the young inventor every possible assistance in the way of facilities and technical collaboration. As it happened, Preece had himself developed a method of telephony without wires, based, as we would now say, on a method of electrical conduction or induction. But that consideration did not weigh with him for one moment. Some of his best engineers were put at Marconi's disposal and they did much to improve Marconi's system, while Preece himself generously did his utmost to publicise the system of the young foreigner. The first outdoor test was made between the roof of the building in St. Martins-le-Grand, now known as the Central Telegraph Office, and a Post Office Savings Bank building in Carter

Lane, south of St. Paul's. This was followed by successful tests over a distance of two miles on Salisbury Plain and, in the following year, 1897, across the Bristol Channel, a distance of nearly 9 miles.

It is, of course, true that Marconi was not the first to use Hertzian waves for signalling. But, in addition to the introduction of various improvements in the details of the receiving apparatus, he was the first [1] to use a long vertical wire as an aerial and the first to insist on the importance of an earthed connection. Among those who had also been working on the use of Hertzian waves for signalling was Professor A. Slaby of the Technical High School of Charlottenburg, Berlin, and I do not think I can identify for you the original features of Marconi's work better than by quoting Professor Slaby's own remarks on the subject. Writing on 'The New Telegraphy' in 1898, he said :—

> 'In January 1897, when the news of Marconi's first successes ran through the newspapers, I myself was earnestly occupied with similar problems. I had not been able to telegraph more than one hundred meters through the air. It was at once clear to me that Marconi must have added something else—something new—to what was already known, whereby he had been able to attain to lengths measured by kilometres. Quickly making up my mind, I travelled to England, where the Bureau of Telegraphs was undertaking experiments on a large scale. Mr. Preece, the celebrated Engineer-in-Chief of the General Post Office, in the most courteous and hospitable way, permitted me to take part in these ; and in truth what I there saw was something quite new.
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> 'In the first place, Marconi has worked out a clever arrangement for the apparatus which by the use of the simplest means produces a sure technical result. Then he has shown that such telegraphy (writing from afar) was to be made possible only through, on the one hand, earth connection between the apparatus and, on the other, the use of long extended upright wires. By this simple but extraordinarily effective method he raised the power of radiation in the electric forces a hundredfold.'

[1] Marconi's absolute priority in the use of an elevated antenna and an earth has recently been questioned as the result of careful study by V. A. Bailey and K. Landecker, who have shown that A. S. Popov published an account of his use of such devices for radio-signalling some months before Marconi. Their conclusion is therefore 'that, if Marconi has any claim to be an inventor of radio-communication, then Popov has prior claim over Marconi.'

It will not be disputed, however, that the main stream of radio development has proceeded from the efforts of Marconi rather than from those of Popov.

In other words, it was the use of a high aerial and the employment of an earthed connection (which in itself approximately doubled the effectiveness of the aerial) which were largely responsible for the greatly increased ranges of radio-communication which Marconi was able to achieve.

From 1897 onwards the ranges of operation effected were steadily increased and it was in connection with the communication at the longer ranges that discoveries of great scientific importance in the field of geophysics emerged. For some time Marconi had held the belief, which was not in accordance with the general scientific opinion of the day, that world-wide communication was practicable. To this end he had constructed at Poldhu, in Cornwall, the most powerful radio station of the day, and in December 1901 he and his two assistants, Kemp and Paget, had the satisfaction of receiving intelligible messages from Poldhu at Signal Hill, in Newfoundland. In this way there was established between Britain and her oldest colony the first long-distance radio link, just as, thirty-three years earlier, the first transatlantic submarine cable link had been established between the same two countries. It was this successful communication round the curvature of the earth that led to the suggestion of the existence of the ionosphere, which, in turn, has prompted the scientific study of upper-atmosperic phenomena during the last two decades.

In the following year, 1902, Marconi reported, in a paper read before the Royal Society, that he had noted pronounced differences between day and night signal strengths. Making observations on the U.S. s.s. *Philadelphia* sailing westward across the Atlantic Ocean, he had noticed no difference between the day and night signals from the Poldhu sending station up to a distance of 500 statute miles. But, at distances of 700 miles, day signals failed entirely while night signals remained strong and were indeed readable up to 2,099 miles from Poldhu. Marconi, mistakenly as we now know, was inclined to attribute the weakness of the day-time signals to the effect of sunlight on the metallic conductors of the sending aerial. Nowadays we should explain these results differently, and invoke instead the influence of the ionosphere. The day-time signal is low, not because of the influence of sunlight on the sending aerial, but because, during daytime, the ionosphere does not reflect appreciably the radio waves of the particular wave-length used by Marconi. At night, when the reflection coefficient of the ionosphere is greatly increased, a substantial signal strength is received at great distances.

Similarly it cannot be claimed that Professor J. J. Thomson was the only worker in 1897 who was studying the question of the identity of the cathode-rays in the discharge of electricity through gases at low pressure. But it was Thomson who first interpreted and unravelled the confusing mass of evidence which surrounded this subject, and who made the final experiment which demonstrated, in a manner everyone accepted, that cathode rays consisted of negatively charged particles, all alike, and all very much smaller, and lighter, than the smallest particle previously known to science, the atom of hydrogen. In the Royal Institution discourse of 1897 Professor J. J. Thomson foreshadowed the electron theory of matter which has prompted all atomic research for the last fifty years. But it has also been due largely to two electronic devices that there has been such phenomenal progress in the field of practical radio—such as broadcasting and television—and also in the employment of radio waves in the scientific exploration of natural phenomena. I refer to the cathode-ray oscillograph and the thermionic amplifying tube. Both of these devices depend on the use of free electrons which are liberated or evaporated from a heated wire source in an evacuated vessel, in a manner first elucidated for us by Sir O. W. Richardson, one of Sir J. J. Thomson's research students. In the cathode-ray oscillograph the freed electrons constitute a kind of electric pencil which can be made to trace out and portray intelligence on a sensitive screen. The intelligence may be known already, as in a television picture, or it may be unknown, as in the case of the wave-form of an atmospheric. The reason the electron beam acts like a practically instantaneous indicator of electric or magnetic events is due to the ease with which it is deflected by electric and magnetic forces, which facility is due to the exceedingly small mass of the electron itself.

In the case of the three-electrode valve the electronic current flowing through it, from the filament source to the collecting plate, can be controlled by means of a perforated grid situated between the filament and plate. By means of an electrical charge on the grid the electronic current flowing through the grid perforations may be altered. The reason it is possible to get amplifications with such a device is due to the fact that the electrons do not follow the lines of electric force. Most of them arrive at the grid distance with such high speeds that, in spite of the local electrical attraction of the grid, they shoot through the holes and are collected by the anode. In other words, the grid does the work, but the anode gets the benefit. This is the essential secret of thermionic valve amplification.

The Use of Radio in the Exploration of Natural Phenomena

I now turn to consider some of the scientific consequences of these practical developments in radio and electronics which started fifty years ago. For this purpose I invite you to accompany me on an imaginary journey, starting at the earth's surface, first to the higher reaches of the atmosphere, then to the sun and finally to the stars, and I shall try to indicate some of the advances in our knowledge on the way. These have resulted from the fact that, while we must make the journey only in our imagination, radio waves can make the journey in reality. But let us first take stock of our experimental assets in the way of apparatus and techniques. The first is our ability to produce radio waves of a great range of wave-lengths by means of thermionic amplifying valves. Moreover, we can direct these waves, especially if they are very short, in any desired direction. We can also cause their emission to take place in spurts or pulses which can be detected again if the waves are reflected back to us by any agency in space. We can also measure, using our cathode-ray oscillograph, intervals of time down to well below a millionth of a second and so, assuming the velocity of travel, measure long distances to an accuracy of well below 300 metres. Changes in the distance of a reflecting surface can also be measured to an even greater degree of accuracy, using radio-wave interference methods. A change of, say, 10 metres in the distance of a reflecting object hundreds of kilometres away can easily be measured in this way. The cathode-ray oscillograph is a most convenient device for measuring echo delay times of the kind I have mentioned. Its electronic pencil can also be used for delineating the time variation of the electric force in a transient train of radio waves, in other words, for portraying the wave-form of any succession of radio waves. The same electronic pencil can also be used in indicating the direction of arrival of a very brief train of radio waves. The normal methods of radio direction-finding are, of course, available for finding the direction of arrival of a sustained train of radio waves, or of a continuous radio noise.

The Investigation of the Lower Terrestrial Atmosphere

Before we leave the earth's surface on our imaginary journey away from it, we might first glance at two applications of radio which are of importance in scientific geophysical investigations. In a radio receiver, sited on the earth's surface, unwanted signals are often experienced due to those naturally-occurring trains of radio waves known as

atmospherics. For many years a certain mystery seemed to surround the origin of these " strays," as they are sometimes called, but I have long held the view that they are due to lightning flashes or thundercloud discharges in the lower atmosphere. In recent years, using cathode-ray oscillograph delineation of wave-form and automatic photography, it has been possible to study the emanation of atmospherics from lightning discharges and to trace the gradual change of wave-form with distance of travel. It has also been possible to correlate these electric field changes with the optical manifestations of the lightning discharge which are revealed by rotating-camera photography.

It is now well known that, in discharges between a thundercloud and the ground, the first electrical event is the occurrence of a leader stroke, from the cloud to the ground, which is of a discontinuous nature. The main discharge then takes place along the ionised trail blazed by the leader stroke. Studies of the electric field changes at different distances have been linked with these two events. The leader stroke is found to be the origin of a series of electromagnetic pulsations of relatively high quasi-frequency, while the return stroke is the origin of the main atmospheric wave-form of lower quasi-frequency.

It is a fact, well known to radio operators listening to weak signals, that atmospheric noise is more troublesome by night than by day. This is due, not to the greater frequency of thunderstorms by night, but to the greater ease with which the atmospherics, originating at great distance, travel effectively by way of ionospheric reflection at night. We must, in fact, picture the atmospheric noise received under such conditions as integrated from distant sources over a wide area. Any land region, for which the local time is afternoon, is likely to be a source of atmospherics when the sun is high. Equatorial land areas are sources of this kind and constitute the earth's major source of atmospheric noise, though these are supplemented at any observing point by a local supply from nearby thunderstorm areas.

In this connection I should like to pay a special tribute to the work of my friend M. Bureau, Director of the French National Laboratory of Radio-Electricity, and his colleagues for their concerted study of the identification of atmospheric sources by radio direction-finding methods. During the years 1940–44, forbidden to use any form of radio transmitter, they conducted their researches on the reception of atmospherics and the localisation of storms, in secret. During the years of resistance in France, and resistance I certainly claim their scientific work to have been, M. Bureau and his colleagues built a network of direction-finding stations which enabled them to identify, by intersection, individual atmospheric sources and so study the travel of thunderstorm areas.

In our own country much use was made of atmospheric detection during the war by the Meteorological Office. It was realised that lightning flashes could be detected up to distances of 1500–2000 km., so that their location by radio methods would provide, not only a means of warning aircraft of thunderstorm positions, but also valuable information to forecasters of air-masses and positions of cold fronts over enemy-occupied territory and over sea areas from which weather reports were not obtainable. Four observing stations were used, located at Dunstable (the Central Forecast Station), Leuchars, St. Eval and Irvinestown (in Northern Ireland). Each was fitted with a cathode-ray direction finder tuned to a wave-length of 30,000 metres, since atmospherics produce more violent effects on long-wave than on short-wave receivers. With the cathode-ray direction finder (the basic principle of which was suggested independently by R. A. Watson Watt and J. F. Herd, by C. E. Horton and by G. L. MacNaughton) the observer sees portrayed as a transient flash on the screen of a cathode-ray oscillograph the direction of origin of the lightning flash which causes the atmospheric. There is actually an ambiguity of 180° in the reading but that difficulty is easily resolved as soon as the bearings from all four stations are plotted. The four stations used during the war were inter-connected by telephone, which permitted the officer controlling the observations to ensure that simultaneous readings were made for individual atmospherics.

As a result of this series of observations it has been possible to identify the frequency of atmospheric occurrence in relation to the warm and cold fronts of an occluded depression. It is found, for example, that there is a maximum at the very apex of the warm sector, suggesting that the ascensional velocity of the warm air is also greatest at this point. It has also been found that there are two sources of maximum atmospheric occurrence behind a cold front, a major maximum at 80 km. and a broad secondary maximum at about 650 km. behind the front.

The other application of ground radio geophysical work is the application of radar for the detection of heavy rainfall areas. Raindrops scatter energy from a beam of radio waves, the scattering being more pronounced the shorter the wave-length. If pulses of centimetric waves are used, the echoes from heavy rainstorms can be detected by way of this back-scattered radiation.

From studies of this kind it has been pos-

sible to distinguish between the two types of thunderstorms, namely, (*a*) air-mass or convective type, and (*b*) cold-front type by the different types of echo-shape portrayed on the cathode-ray oscillograph screen. Echoes from type (*a*) thunderstorms appear on the screen as single areas, while type (*b*) areas are indicated by a narrow bright area of characteristic appearance marking the position of the thunderstorms along the cold front. It should, of course, be emphasised in this connection that radar methods of this type really detect precipitation areas and not the occurrence of lightning, and echoes are sometimes obtained from cold fronts along which rain is falling though thunderstorms have not actually developed. It should also be pointed out that this type of rainfall detection, since conducted with extremely short waves, has only a limited range since it is necessary for there to be a direct path for the radio waves between the radar station and the rainfall area.

The Use of Radio Waves in Aerial Surveying

During the war there was developed at the Telecommunications Research Establishment, by Dr. R. A. Smith and his colleagues, a whole series of new radio navigational aids. One series of these was designed to permit the accurate location of an aircraft by radio means alone. Some of these navigational aids, used during the war for 'blind bombing,' have been recognised already as having valuable functions, in conjunction with aerial photography, for surveying territory which is normally inaccessible to ground parties. In one respect the survey problem is easier than that of blind bombing as the position of the aircraft only is required and not its direction and speed of flight.

The most accurate radar methods of position fixing are those known as 'G/H' and 'Oboe.' These depend essentially on measuring with high precision the range from two fixed stations. In the former the measurements are made in the aircraft, the ground stations being merely pulse repeaters; in the latter the aircraft carries a pulse repeater and the measurements are made at the ground stations. The range measurement is made as follows. A train of very short pulses is sent out from a transmitter. They are received by the repeater and retransmitted with a small known delay. They are then received at the location of the transmitter and the whole time between transmission and reception is measured in terms of calibration marks generated by an oscillator of very high accuracy. The velocity of propagation of radio waves in the atmosphere is accurately known, and, from a knowledge of this and the delay in the repeater, the distance of the repeater from the transmitter may be determined with a high order of frequency. For 'G/H' this accuracy is about $\pm$ 50 metres and for 'Oboe' an accuracy of about $\pm$ 10 metres is possible.

In both systems the aircraft is made to fly as closely as possible on a circle of constant range from one of the ground stations, its position being determined by noting its deviation from this circle and its range from a second station. For the purpose of photographic survey the area to be explored is divided into a series of circular 'strips' arranged to provide photographs with about 60 per cent. overlap between strips. These strips are centred on the 'tracking' station and the aircraft flies along circles so arranged that it will photograph each strip in turn. As it flies along each strip a series of photographs is taken at distances from the 'releasing' station so arranged that each photograph will overlap about 60 per cent. with the previous one. At the instant of taking each photograph the exact position of the aircraft is recorded by photographing the radar display giving the range from the two stations. By means of the overlapping photographs the tilt of the aircraft may be determined so that all the data required for locating a point on the ground with respect to the fixed stations is available.

Experimental surveys using both 'G/H' and 'Oboe' have been made in this country —in particular accurate maps of Anglesey have been made with both systems. Although these do not compare in accuracy with the best maps by triangulation they are very good, errors being of the order of 100 metres at most and usually only 20 or 30 metres. This is very much better than is available for large areas of the world. The radio technique enables such maps to be made very much more rapidly than by triangulation and, of course, is available for regions which are not accessible to ground survey parties. The method will therefore be of immense value in charting areas of the world for which no accurate maps now exist.

The Travel of Ultra-Short Radio Waves near the Earth's Surface

The recent intensive study of the travel of very short waves, before, and especially during, the war, has disclosed some remarkable new phenomena in the lowest layers of the atmosphere. It was already known before the war that the B.B.C. Television Station, operating on a wave-length of 6 to 7 metres, was heard at increased distances at night in fine weather, between about sunset and midnight; but no one had quite realised that there are

frequently built up, near the earth's surface, refracting layers which are sufficiently potent to bend radio rays round the curvature of the earth.

The most striking manifestations of these effects were noticed during the war when it was found that, under certain fine-weather conditions, it was possible for a coastal radar station set to receive echoes from a ship which had passed well beyond the horizon. During the war such matters were the subject of intensive study by the Ultra-Short-Wave Panel of the Ministry of Supply; and, by both radio experiments and direct meteorological measurements, it was found that there is frequently a horizontal stratification of the lowest layers of the atmosphere, characterised by marked vertical variations in temperature and water-vapour content, which causes a beam of radio waves to travel in a curved path, concave to the ground.

If, for example, the temperature increases with height at the rate of 1 degree in about 9 or 10 metres, or the atmospheric water-vapour pressure falls by as much as 1 millibar in 30 metres, the diminution of refractive index with height is such as to cause a radio ray, starting out horizontally, to follow the curvature of the earth. The most marked negative gradients of atmospheric refractive index obviously occur when a strong temperature inversion and a rapid lapse rate of water vapour obtain simultaneously.

The need to correlate radio phenomena with meteorological conditions has prompted the radio-physicist and the meteorologist to join forces in attacking the problems of what is practically a new subject, radio-meteorology. It is, however, already clear that the vagaries of ultra-short wave transmission have led the meteorologist to recognise important phenomena in the lowest regions of the atmosphere which he had previously overlooked.

Radio Exploration of the Higher Atmosphere

Let us now leave the lower atmosphere and proceed upwards to a level exceeding 100 km., where the air is relatively strongly ionised due to the absorption of solar radiation there. The most regular solar ionising agent is ultra-violet light though, on occasion, this is accompanied by charged particles of atomic magnitude. Since 1924–25, when the existence of the ionised region of the upper atmosphere was first proved experimentally, the ionosphere, as it is now called, has been the subject of exploration by means of radio waves. In 1927 it was shown that there existed more than one layer in the upper atmosphere, and, since then, the ionospheric structure has been investigated in some detail. The way that structure varies with the hour of the day, with the season of the year and with the sunspot cycle has been followed. From the results of such exploration together with information derived from the study of geomagnetism and auroral manifestations, there is being gradually accumulated a vast body of information relating to the physical condition of the higher atmosphere and to the changes which take place there as a result of the regular, and irregular, variations in the radiations received from the sun.

The structure of the ionosphere above any particular observing point on the earth's surface is most conveniently investigated by projecting waves vertically upwards, using a suitable aerial, and measuring the group-time of flight of the waves on their journey up to the reflecting stratum and back. By multiplying the group-time by the velocity of light we obtain what is termed the equivalent path (P′) which is evidently equal to twice the equivalent height (h′). The curve expressing the relation between the equivalent height h′ and the electric wave frequency f is an important ionospheric index since from it can be deduced much information relating to the amount and distribution of the electrons in the layers. There are now many stations all over the world securing daily, and sometimes hourly, experimental data of this type. Additional information relating to ionospheric conditions can also be obtained from measurements of the intensity and state of polarisation of the reflected waves on their arrival back at ground level.

Generally speaking, we may say that, as the frequency is increased, the electric waves used in ionospheric sounding penetrate further into the layer from which they are reflected. Ultimately, however, with increasing frequency, the layer is pierced at what is called the critical frequency. From the value of the critical frequency the maximum ionisation in the layer may be deduced. From (h′, f) data, therefore, much can be found concerning the relation between ionisation density and height in the ionosphere above the point of observation. The thickness of the layers can be estimated while the ionisation maximum can be accurately determined.

As already mentioned, there are two principal layers in the ionosphere, the E and F Layers, at 100 and 230 km. respectively, though there is also evidence suggesting the existence of a much more weakly ionised region (D Layer) at 60–70 km. and thus below the E Layer. The D Layer acts chiefly as an absorbing region but the reflection of extremely low-frequency waves has been detected from it. From measurements of the

critical frequencies of the E and F Layers it is possible to study the temporal variations of their maximum electron densities. It is found, in this way, that the ionisation in these two layers is subject to a marked solar control. The ionisation in the E Layer, for example, starts to increase round about sunrise, reaches its maximum at noon and then wanes as the sun sets. Through the night the ionisation sinks to a low value which is not replenished till the dawn, though there are often observed nocturnal sporadic increases of ionisation which must be due to other than direct solar influence. The F Layer likewise exhibits a marked solar dependence. Its ionisation, has been found to be generally greater than that of the E Layer though it is subject to considerable irregularities. Although the ionisation increases rapidly round sunrise it does not always reach its maximum at noon. Through the night the ionisation in the F Layer does not decay relatively so rapidly as does that in the E Layer and the minimum value, which obtains just before dawn, is usually appreciable and measurable.

The general trend of the diurnal variations of ionisation and its marked correlation with sunrise and sunset leaves little doubt that the major agency responsible for the ionisation is of solar origin and travels in straight lines. It must therefore consist of ultra-violet light or neutral particles. Observations on the occasions of solar eclipses have, however, shown that the ionisation in the E and F_1 Layers [1] immediately diminishes as the sun's disc is obscured, from which it may be deduced that the responsible ionising agency is ultra-violet light. The corresponding evidence for the case of the F_2 Layer is not so conclusive and the choice between ultra-violet light and neutral particles is still in dispute. The fact that the greater part of the electron production in the ionosphere is due to the solar ultra-violet light which is absorbed there, invests the study of the ionosphere with special importance since it becomes a study of a particularly interesting part of the sun's spectrum which cannot be detected at ground level. It also becomes the study of certain atomic processes such as photo-ionisation, recombination of ions and attachment of electrons to neutral molecules under mean-free-path conditions which cannot be realised in the laboratory.

The solar control of the ionosphere is shown also by the changes in ionisation which take place during the 11-year sunspot cycle, the ionisation waxing and waning with the sunspot activity. From the sunspot minimum of 1934 to the maximum of 1937 the ionisation density of the E and F_1 Layers increased by as much as 50 to 60 per cent. This implies a still greater increase, of 120 to 150 per cent., in the intensity of the solar ultra-violet light responsible for their formation, which is in striking contrast with the constancy of solar radiation received at ground level during the same period. This sunspot cycle variation of the E and F_1 Layers is of special interest since it has been known for many years that the regular daily variations of the earth's magnetic field are about 50 to 60 per cent. greater at sunspot maximum than at sunspot minimum. We can now see that these magnetic changes during the solar cycle are the result of the changes in upper-atmospheric conductivity which is itself proportional to ionisation concentration.

Balfour Stewart's theory, that the small daily regular changes of terrestrial magnetism are due to currents flowing in the upper atmosphere has therefore received ample confirmation from radio investigations. He explained the currents as arising from a species of dynamo action, due to the rhythmic tidal motion of the layer itself across the earth's permanent magnetic field. It has been known for many years that the terrestrial atmosphere is the seat of large-scale forced oscillations due to gravitational action of the sun and the moon. The frequency of the oscillations caused by the periodic force due to the sun is 730 cycles per year (two cycles per day) and the corresponding figure for the moon about 705 cycles per year. These oscillations can be detected at ground level, being reflected in the barometric readings. For example, the variations in barometric pressure due to the semi-diurnal oscillations due to the sun can be readily seen on the records of equatorial stations. The effects are, however, relatively small and, in any case, it does not follow that the tidal motion is the same at all atmospheric levels.

Fortunately, using radio methods, it has been possible to make at least a start on the direct study of tidal action at high levels, for in 1938 R. Weekes and I showed that the E Layer rises and falls by about 1 km. with a lunar tidal motion, twice during each lunar day. This value was unexpectedly large, but quite recently D. F. Martyn has repeated the experiment in Australia and found lunar tidal motion of about the same amplitude.

There is one more type of measurement which may be made concerning conditions at high atmospheric levels. It was recognised in 1925 that, if the free electric charges in the ionosphere are of electronic mass, the earth's magnetic field would have a profound effect on the refracting properties they confer on the ionised medium. The development and

[1] The F Layer usually exhibits a dual structure of two overlapping strata, termed F_1 (lower) F_2 (upper).

practical verification of this magneto-ionic theory has shown that we must regard the ionosphere as a doubly-refracting medium in that a radio wave entering it is split up into two characteristic components polarised in opposite sense. For example, under certain conditions this magnetic influence causes the splitting of an incident radio pulse into two separate reflected pulses which arrive back at the ground with slightly different delay times. The study of magneto-ionic splitting and the different refractive behaviour of the ionosphere as regards the two components have led to a method of measuring the earth's magnetic field at the level of reflection. Using this method it was possible to show that the magnetic field intensity is about 10 per cent. less at a height of 300 km. than it is at the ground. This, of course, agrees with expectation ; but I believe that, with more refined measurements, it may be possible to get further information concerning small variations of the earth's field at great heights as well as quantitative indications of the relative rôles played by electrons and ions.

The Radio Detection of Meteor Trails

Before we leave the subject of the earth's higher atmosphere we may note the recent work, carried out in Britain, on the radio detection of meteor trails, using radar equipment originally designed for the detection of aircraft from the ground. A notable opportunity occurred for making observations of this type during the Giacobini-Zinner meteor shower, last October, when radio studies were made at three stations in England, at Manchester, Richmond and Slough. A meteorite has been reported as falling to the ground in the Grand Canyon National Park, in America, during this particular shower. Measuring two inches long and an inch and a half wide, the meteorite was quite hot when dug out of the ground where it had become embedded. From the time of fall reported, it would appear that it entered the atmosphere at the peak of meteor shower activity as disclosed by the radio observations made in England. The great advantage of the radio method of meteor detection is that it can be conducted regardless of the weather and also equally by day as by night.

The success of radio methods for the detection of transient ionisation bursts due to meteors in the upper atmosphere suggests that, with equipment of very much enhanced sensitivity, it might be possible to detect radio reflections from ionisation bursts in the earth's atmosphere due to the entry of very energetic cosmic rays. Such an attempt is already planned by a team of workers at Manchester, under Dr. A. C. B. Lovell, as an extension of their work on meteor detection. Success in such an experiment would provide a powerful new technique for the investigation of the cosmology of cosmic rays.

Radio and Solar Exploration

As we have seen above, the radio exploration of the ionosphere has shown that large changes take place in the intensity of the solar ultra-violet light during the sunspot cycle. No such changes occur in the visible and thermal radiations received from the sun on the earth's surface. Radio studies have also indicated some of the violent changes which occur at high levels due to the entry of charged solar particles in the terrestrial atmosphere. Another radio discovery concerning solar emissions relates to the marked bursts of ultra-violet light which have been found to accompany solar flares associated with sunspots. Such bursts of ultra-violet light are found to produce temporarily enhanced ionisation in the D Layer of the ionosphere, which causes sudden radio ' fade-outs,' for circuits traversing the sunlit hemisphere. Such examples illustrate the way in which the interests of the solar physicist and the radio-physicist are converging.

Quite recently an entirely new solar phenomenon has been discovered using radio methods. It has long been recognised that, since the sun emits visible and thermal radiation corresponding to a black-body temperature of 6,000° K., it must also correspondingly emit radio waves corresponding to the same temperature. But calculation shows that such radio wave intensity on a wave-length of, say, 5 metres, would be so small as to be undetectable with present-day techniques. J. S. Hey and I have, however, shown that during periods of solar activity, extremely strong radio emissions occur from sunspot areas, the maximum effect being observed on a wave-length of the order of 5 metres. Such abnormal radio emissions are more than a million times stronger than we should expect if the sun radiated as a black-body at 6,000° K. A sunspot is, in fact, the most powerful ultra-short wave radio station known, its power being much greater than a million kilowatts. Moreover, it has been found, in experiments conducted in England in February of last year, that sudden large increases in intensity of solar radio noise have been observed to occur simultaneously with solar flares and radio ' fade-outs.'

There is evidently here a solar phenomenon of great interest and importance, and various theories have been advanced to explain the mechanism of the origin of solar radio noise, but agreement on the subject is still lacking.

Radio Noise from the Milky Way

Finally we may note the reception on the earth of ultra-short-wave radio noise originating in the Milky Way. Seventeen years ago K. G. Jansky, of America, when making observations on the direction of arrival of terrestrial atmospherics, noted that small residual disturbances remained when his antenna pointed in certain directions. At first he was inclined, as we now know erroneously, to attribute this noise to the sun. In later work, however, he was able to show that the sun had no effect and that the maximum disturbance came from the direction of the Milky Way. This result was later confirmed by G. Reber who greatly improved the angular resolution of the observations and also made an estimate of the intensity of galactic radio noise.

During 1945, Hey, Phillips and Parsons in England modified a British radar receiver for the measurement of galactic noise on a wavelength of 5 metres and were able to show that the maximum disturbance originates in Sagittarius and a minor one in Cygnus. The same authors have discovered that the radiation from Cygnus is subject to a short-period fluctuation whereas that from Sagittarius is relatively constant.

The origin of galactic radio noise is evidently a subject of great astronomical importance and is receiving attention by many workers in different parts of the world. Two modes of origin have been suggested. According to one theory the radiation arises from ' free-free ' transitions of electrons in the ionised hydrogen gas which permeates interstellar space. The other theory is based on the discovery, mentioned above, of the enhanced radio emissions from sunspot areas, and assumes that galactic radio noise is the integrated effect of such outbursts from the stars in the Milky Way. Neither theory has received general acceptance up to the present.

Conclusion

On September 14, 1859, His Royal Highness the Prince Consort, addressing this Association as its President, referred to its meetings as 'throwing open the arena to the cultivators of all the sciences, to their mutual advantage : the Geologist learns from the Chemist that there are problems for which he had no clue, but which that science can solve for him ; the Geographer receives light from the Naturalist, the Astronomer from the Physicist and Engineer, and so on.' In this address I have tried to illustrate by some examples the truth of this illustrious pronouncement on the interdependency of the sciences. I have tried to show how the work of the radio-physicist has become linked with that of the meteorologist, the solar physicist and the astronomer. The radio-physicist has indeed become deeply indebted to the work of his colleagues in these allied subjects, but I hope it can fairly be said that he has contributed something of value in return.

SECTION B.—CHEMISTRY

SCIENCE AND THE COLONIES

ADDRESS BY

J. L. SIMONSEN, D.Sc., F.R.S.

PRESIDENT OF THE SECTION

Our meeting to-day can best be regarded as a continuation of that so abruptly terminated in 1939, and I appreciate greatly the honour of being asked to be the President of this Section. Dundee early showed its interest in the British Association, and it is just 80 years ago since it first enjoyed the City's hospitality. On that occasion Professor Anderson was the President of this Section. When next we met here, in 1912, Professor Senior gave a discourse on the nature and method of chemistry. Much of what he then said is true to-day.

Addresses from this Chair have in the past concerned themselves with a variety of themes. Some have been devoted to a consideration of the more outstanding contributions to chemical knowledge during the previous twelve months, others to some branch of our science which the President has made more peculiarly his own, but, so far as I can discover, the application of the scientific method to the solution of the many problems of our Colonies has not so far been discussed. In attempting to do this I hope to interest a wider public than might be the case if I had chosen one of only scientific importance.

On this occasion the subject would appear to be particularly appropriate since just a year ago two important conferences were held in London, the Royal Society Empire Scientific Conference and the Official Commonwealth Scientific Conference. Many of the resolutions approved at these conferences, if they are, as we may hope, implemented cannot fail to influence profoundly not only the future of this country and the Dominions but also of our Colonies. Success can, however, only be achieved if there is the fullest co-operation not only in research but also in the utilisation of the results of such research.

It may not be unfruitful to look for a short time into the past and to trace the beginnings of the application of science to the varied problems of the overseas Empire. To get a true picture we must bear in mind that many of the now self-governing members of the Commonwealth were at that time Crown Colonies and that within their territories there was little industrial development. They were regarded essentially as sources of raw materials for the mother country. Furthermore, it was not considered a function of government to engage or even support, except by small grants, scientific research. It was only during the first World War that governments first realised that their active participation was necessary, and this resulted in the formation of the Department of Scientific and Industrial Research. The work of this great organisation is too well known to require any elaboration by me. We have now parallel bodies in the great Dominions and in India.

An important landmark in the application of science to the colonies was the foundation in 1883 of the Imperial Institute, a national memorial to the jubilee of Queen Victoria. In the first issue of the *Bulletin* of the Institute (May 1, 1903), the functions of the Institute were stated to be: 'The principal object of the Institute is to promote the utilisation of the commercial and industrial resources of the Empire by arranging comprehensive exhibitions of material products, especially of India and the Colonies, and providing for the collection and dissemination of scientific technical and commercial information relating thereto.'

I do not propose to give a detailed account of the work of the Institute or of its vicissitudes. It will suffice to record that the necessity for research on colonial products was fully recognised by its first Director, the late Sir Frederick Abel and by his successor, Sir Wyndham Dunstan. Laboratories were provided and much original research was carried out in them, whilst the collaboration of other investigators was obtained. I would mention in particular the valuable studies on the natural colouring matters which we owe to the late Professor A. G. Perkin, whose materials were largely supplied by the Institute. Possibly the most valuable of the earlier activities of the Institute was the organisation of geological surveys in the

African colonies and the assistance which it gave to the growing of cotton in the Empire. Unfortunately, the work of the Institute has always been handicapped by the lack of adequate financial resources and in recent years original research has no longer formed a part of its activities. It has, however, continued to be a main centre for the collection and dissemination of scientific, technical and commercial information. The great importance for such a centre was emphasised at the meetings of the Royal Society Conference, and this subject, as you are doubtless aware, received strong support from this Association. It is obvious that whatever form the reorganisation of the Institute may take in the future, this activity is likely to prove of increasing importance.

It has during recent years become clear that if the Colonies are to be developed and play their full part in the world's economy, they can no longer continue to be regarded solely as prime producers. Whilst it is recognised that agriculture, with its essential feature the growing of foodstuffs, must continue to be the main industry of the Colonies, as indeed is true also for many of the Dominions, the introduction of other industries is essential. Whilst the development of these in their early stages is dependent mainly upon the application of known processes, their future progress will require research of a high order, and this is especially true of agriculture, which must be highly efficient, since it is not improbable that this will provide the main source of their industrial raw materials.

In spite of the major preoccupations of war the government in this country gave careful consideration to these colonial problems, and they rightly reached the conclusion that only with the assistance of science and the men of science could they be solved. In 1942 the the Colonial Products Research Council was formed, and it held its first meeting in January 1943. It may not be without interest to record here a part of its terms of reference :—

'To review the field of Colonial production and to advise what colonial raw materials are likely to be of value to the manufacture of intermediate and other products required by industry ; in consultation with the Director, to initiate and supervise researches, both pure and applied, on such products, and generally to consider how, by the application of research, greater use can be made of them.'

Whilst the term 'raw materials' in the terms of reference, if interpreted in its full sense, includes minerals, animal and vegetable products, I propose to-day to confine my remarks more especially to the last, since a consideration of the first two subjects would take me into fields of science upon which I do not feel competent to address you. With regard to minerals it will suffice to say that in the future economy of many of the colonies they are likely to play a predominant part. Much now depends upon a detailed geological survey, still so sadly lacking, and so far as the African Colonies are conerned upon the full utilisation of the admirable facilities available in the Union of South Africa for experiments on their processing.

As raw materials for the chemical industry plant products can be of two kinds, primary products such as sucrose (sugar) vegetable and essential oils or secondary (waste) products, bagasse, straw, shells of nuts. We must for the provision of these depend upon two important factors, water and an efficient system of agriculture. Perhaps, not unnaturally, we in this country are not sufficiently water-minded, but we must recollect that the colonies are in the greater part situated in the tropics. In many of them water is not too abundant and a systematic survey is required, not only of its availability for irrigation but also as a source of hydro-electric power. I would suggest also that it might prove profitable to study in how far some of the saline water from inland lakes could be rendered suitable for irrigation by the use of resin filters.

In making a survey of the plant products of the Colonial Empire it is at once apparent that the most abundant of these are the carbohydrates, starch and sugar. Any large scale chemical industry based upon plant products must look to these for their basic raw materials. Starch already finds an extended application in industry and it differs considerably in its properties depending upon its source. New uses are also likely to be developed. The elegant methods evolved in the Birmingham laboratories for the separation of the two constituents, amylose and amylo-pectin, have rendered these readily accessible products. Amylose resembles cellulose closely in its properties and could doubtless for many purposes replace this. We know very little of the nature of the starches present in the starch-producing plants of the tropics, and a survey of them is urgently required. Preliminary investigations in this direction are in progress, but in view of the importance of the subject they need to be considerably extended. The work is tedious and it can be carried out only in the territories where the plants occur. We cannot assume that other starches with properties as unique as those of arrowroot will not be found.

When we turn to sucrose we find that in the past, apart from its use as a foodstuff, its industrial application has been confined almost solely to the fermentation industries. In

addition to its utilisation for manufacture of alcoholic beverages, industrial alcohol and other solvents, it is now a source of many important acids. Much consideration has been given to the possibility of using carbohydrates for the manufacture of power alcohol or similar products for use in internal combustion engines. This may prove possible to a very limited extent, but the cost of power from such materials would be prohibitive and the area required for the cultivation of the necessary plant products could ill be spared from that required for the growing of foodstuffs. Here, in parenthesis, I would mention that, should the cost of molasses rise too greatly, it is doubtful if they can compete as a source of alcohol with ethylene from the gases resulting from the cracking of petroleum. This is especially true since the methods for the manufacture of alcohol and other chemicals from ethylene and also from acetylene have been greatly improved.

It is somewhat remarkable that although sucrose is the organic chemical produced in a pure state on the largest scale of any in the world, until recent years very little attention has been directed to the possibility of utilising it as a raw material for the chemical industry. Active work with this object in view is now in progress both in this country and in the United States. We are fortunate that for many years this country has led the world in the study of the chemistry of the carbohydrates and, taking advantage of this, the Colonial Products Research Council has, since 1943, had a team working at Birmingham on this fundamental problem under the direction of Professor Sir Norman Haworth and Dr. L. F. Wiggins. The sucrose molecule is complex and we do not expect rapid or spectacular results, but some progress has been made. In one derivative of sucrose, levulinic acid, we have a substance which in the form of its sodium salt is an excellent anti-freeze, superior in many respects to ethylene glycol. From this acid also compounds have been prepared which show promising chemotherapeutic properties. Other derivatives of sucrose may find application in the plastics industry. The processes required for the preparation of some of these substances are comparatively simple and could be carried out readily in the territories in which the sugar cane is cultivated. This would undoubtedly cheapen their manufacture since research has shown that in many cases the crude cane juice can be used in place of the crystallised sucrose. We may anticipate that in a few years sugar will once more be produced in quantities far in excess of that required for nutritional purposes, and by that time our knowledge of the new developments referred to above, and probably others, will be sufficiently advanced to enable them to be developed on an industrial scale.

I do not propose to bore you with an account of the other investigations which are being carried out on Colonial products but there is one activity of the Colonial Products Research Council to which I must refer. During the course of a short visit which Sir Robert Robinson and I made to the Caribbean in 1944 we were impressed by the important part which microbiology might play in the development of the economy of the West Indies and also of the other Colonies situated in the tropics. Microbiology has, in this country, been a Cinderella amongst the sciences, and its importance has only come to be fully recognised with the discovery o penicillin and the other valuable antibiotics now being studied so vigorously. Facilities both for the training of microbiologists and for research in this subject are in this country somewhat limited. With the recognition of its importance to the Colonies the Colonial Products Research Council decided to open a Microbiological Research Institute in Trinidad. This will, I believe, be the first research institute in the British Commonwealth dealing solely with the subject, and it will have as its first Director, Dr. A. C. Thaysen, whose work in this field is well known. As chemists we are accustomed to associate this science mainly with the fermentation industries, but the flavour of our tea, cocoa and tobacco is dependent largely also upon the action of microflora. It is possible also that the *Fusarium*, responsible for the Panama disease which attacks the banana, may be open to biological control. An *actinomycete*, first isolated in the West Indies, has been found to destroy this *Fusarium*, and it is now being actively studied from both the biological and chemical aspects jointly by Dr. Thaysen and by Dr. A. H. Cook and his collaborators in Sir Ian Heilbron's laboratory.

We can anticipate also that this Institute may be able to assist in the solution of some of the difficult problems associated with soil fertility. Recent research [1] is providing evidence that the polysaccharides, resulting from the action of the soil microflora, play an important part in the formation of the soil humus. Is it too optimistic to anticipate that this joint biological and chemical attack on the conditions present in the soil may provide new methods for the prevention of the impoverishment of the soils so widespread in the Colonies? It is intended that this Research Institute shall be a centre for microbiological research not only for the Colonies but for the Commonwealth as a whole.

[1] Haworth, Pinkard and Stacey, *Nature*, 1946, **158**, 836; Geoghegan and Brian, *ibid*, p. 837; Lochead *et al.*, *Canadian J. of Research*, 1947, **25B.**, 20.

During the course of our survey of the colonial plant products our attention was not unnaturally directed to the very large number of plants to which medicinal properties have been attributed. In some cases the reputed action of the plant is religious in its origin, in others such action as they may have, is due to the presence of tannins or mineral salts, but there remain many which require further investigation. Synthetic organic chemistry, with its attention to chemotherapy, has replaced many drugs previously obtained from plants. I need only mention the antimalarials, more especially paludrine. This new drug, probably the greatest contribution of British chemistry in the field of chemotherapy and one which may revolutionise life in the tropics, is due to Dr. F. H. S. Curd and Dr. F. L. Rose and their collaborators working in the pharmaceutical laboratories of Imperial Chemical Industries Ltd. In my opinion the special merit of their achievement is that they have broken away from tradition. Unlike previous synthetic antimalarials, paludrine has no structural resemblance to quinine. It would appear to be highly improbable that quinine can any longer be regarded as the drug of choice in the treatment of malaria. Such progress does not, however, in my opinion, diminish the necessity for a further study of the constituents of the plants with which medicinal properties have been associated. The application of the modern technique to this problem should make it a fruitful field of research both for the chemist and the pharmacologist. Investigations of this character will not only be of interest to the structural organic chemist but may be of assistance also to the taxonomist.

My attention was first directed to the latter possibility during my investigations on the constituents of the essential oils derived from the *Cymbopogons*. These grasses are difficult for the systematic botanist to identify although they can be readily differentiated by the constituents of their essential oils. For example, the two grasses, *Cymbopogon Martinii* Stapf (var. *motia*) yielding palmarosa oil is indistinguishable in the herbarium from *C. Martinii* Stapf (var. *sofia*), which yields a ginger grass oil of little value. Since the two oils have very different constituents they can, however, be readily characterised in the laboratory.

Some years ago [1] I ventured to suggest that comparative chemistry might be used to assist the taxonomist, and this possibility has been discussed in two Sectional Presidential Addresses to this Association. In 1929 Barger [2] expressed the view that chemistry was likely to be of little value to the systematic botanist. He recognised that it had proved of use in the classification of the lichens and of the eucalypts, but he was unable to trace any connection between chemical structure and botanical classification in the case of the alkaloids.[3] The subject of chemical constituents and taxonomy was considered in much greater detail by Hill [4] in 1930 at the Bristol meeting of the Botanical Section. He recorded many instances where comparative chemistry had been of great assistance to the systematic botanist. In spite of the respect which I have for any opinion expressed by so great an authority as Barger, my own view is unchanged. The investigations of British chemists have in the past made great contributions in this field. We have the classical work of Baker and Smith, so ably continued by Penfold on the eucalypts. They have traced a relationship between the venation of the leaves and the constituents of their essential oils. A determination of the latter enabled them to define the species, and their classification of the eucalypts is essentially one based upon chemistry. Even wider in its scope has been the work of Sir Robert and Lady Robinson on the anthocyanins. The elegant and delicate methods of analysis which they have developed has made their work not only of value to the systematist but also to the geneticist, and I do not doubt that with a return to normal times we shall see it utilised to a much greater extent. Finally, I would refer to Hilditch's researches on the constitution of the glycerides in the animal and vegetable oils and fats. My views have received strong support in a recent publication by Darnley Gibbs.[5] He has provided conclusive evidence that the botanist can no longer disregard the nature of the chemical constituents in his classification of plants. If, however, chemistry is to be in a position to afford this assistance, a refinement and simplification of our methods of analysis is necessary. The possibility of this is well illustrated by the work of the Robinsons.

The chemist cannot only be of assistance to the botanist but also to the zoologist. Already Ford [6] has shown that in the case of butterflies the classification based upon morphology corresponds with the chemical character of their pigments whilst Munro Fox [7] has shown that the difference in their hæmoglobins can be used to differentiate the several species of the crustacean genus *Daphnia*. I would direct attention also to the important results obtained recently by

[1] *Proc. Ind. Sc. Congress*, 1928, p. 9.
[2] *Brit. Assoc. Rep.*, 1929, pp. 51–63.
[3] *Cf.* Manske, *Canadian J. of Research*, 1946, **24B.**, p. 66 and earlier papers.
[4] *Brit. Assoc. Rep.*, 1930, pp. 191–218.
[5] *Trans. Roy. Soc. Canada*, 1935 [iii], **29, V,** 71.
[6] *Proc. Roy. Ent. Soc. London*, 1941, **16,** 65; 1942, **17,** 87; 1944, **19,** 92; *Trans. Ent. Soc. Lond.*, 1944, **94,** 201.
[7] *Nature*, 1946, **157,** 511.

Erdtmann [1] in his detailed study of the constituents present in the wood of conifers and in pine needles. From these he has isolated substances showing marked fungicidal properties. We may well enquire if these are natural timber preservatives. Erdtmann has further found that many geraniol derivatives act as fungicides. We shall look forward with interest to the continuation of this work.

I would suggest that considerations of this character would alone warrant a detailed study of the rich flora of our Colonies even if we do not thereby find new products of economic value. But one further and no less important branch of research may profit from a more detailed study of plant constituents. We are still in the main ignorant of the part which they play in the plant metabolism. We have, it is true, some knowledge regarding the carbohydrates and fats but little definite information regarding the essential oils and alkaloids, although Robinson's theory as to the mechanism of the formation of the latter is undoubtedly correct. It is possible that a successful attack on problems of this nature may now prove possible by the use of isotopes. Only when we are fully cognisant of the part which the plant constituents play in the plant economy can agriculture be placed upon a really sound scientific basis.

In concluding this brief and, I fear, somewhat disconnected survey of some of the many problems relating to the application of science to the Colonies, I must refer to one aspect of primary importance, and one upon which its success must in large measure depend, namely the health and well-being of the peoples. It is but a platitude to say that the health of a people depends upon an adequate supply of nutritious food and upon the prevention of disease. Both are dependent upon science and in neither respect can the conditions in the Colonies be viewed with complacence. Chemistry can play a major part in their improvement but only if it is used on an adequate scale, as our experience during the war has shown. Our scientific efforts should, in my opinion, be applied first to these fields.

If we are to have an adequate supply of food, it is of course obvious that we must have an efficient system of agriculture, but this will be of little gain if, after the crops are harvested, we lose much of them by pest infestation. It has in the past been too little realised how great is the loss of foodstuffs by insect, fungoid and rodent attack. It is estimated that, of the annual crops of cereals, oil seeds, beans, etc., some thirty million tons a year are lost in this way or, in other words, there is an average total loss of some 3 to 5 per cent. of the world's food production. The loss naturally varies in different countries, in Canada it is about 1 per cent., but in Kenya the loss of maize may be as much as 10 per cent. and in East Africa about one-third of the total production is lost in this way. These figures suggest that improved methods of agriculture together with the prevention of soil erosion will have little effect if we do not at the same time prevent this loss. Fortunately we are acquainted with methods which can do much to mitigate it if they are scientifically applied. We can reduce the moisture content of grains before they are stored, we can see that adequate storage accommodation is available, we can see that it is free from insect infestation prior to storage and inaccessible to rodents. Deinfestation before storage can be effected with various chemicals, but unfortunately many of these are also toxic both to man and animals. In some cases, for example hydrogen cyanide and methyl bromide, the toxicity is very high, but we know how to overcome any risks which may be attached to their use. The toxicity of the newer and most valuable insecticides, gammexane and D.D.T.[2] is apparently very low and it is doubtful if they involve any danger to man in the quantities usually employed. Unfortunately accurate knowledge on this point is still lacking and it will require long term experiments to determine whether they can act as cumulative poisons. Until such evidence is available it is obvious that their use in direct contact with foodstuffs cannot be permitted. This may appear to be an ultra-cautious attitude to adopt, but the recent work of Mellanby [3] on the cause of dog hysteria justifies it. It is disturbing to find that this is caused by the ingestion of flour bleached by a well known and widely used method. Dare we assume in the absence of similar evidence that the continued consumption of small quantities of these new insecticides may not expose us to danger? If on further investigation these insecticides are found to be safe and non-toxic we shall have a weapon which should largely prevent loss of foodstuffs by insect attack.

Of even greater importance than the prevention of the loss of food is the control of insect-borne diseases of man and beast which so seriously undermine their health and which render large areas of the Colonies uninhabitable. The field operations in Burma and elsewhere have proved conclusively that a large measure of control is possible, and it is doubtful otherwise if the campaigns in these tropical areas could have been fought with success. Our two foremost enemies are un-

[1] *Naturwiss.*, 1939, **27**, 130, and private communication.

[2] Gammexane is the trade name for hexachloro*cyclo*hexane: it is known also as 666. D.D.T. is an abbreviation of dichlorodiphenyltrichloroethane.

[3] *Brit. Med. J.*, 1946, p. 885.

doubtedly the mosquito and tsetse fly. Since Sir Ronald Ross' epoch-making discovery that the mosquito was responsible for the transmission of malaria and the subsequent proof that it was responsible also for yellow fever, large scale measures for its control have been successfully undertaken. These measures cannot, however, be generally applied, and I believe that a new era has now arrived by the discovery of the new synthetic insecticides. Admittedly we have still much to learn as to their method of application but the experiments carried out during the war and since its termination have given results of the greatest promise. I would venture to suggest that we already have sufficient knowledge to enable us to eradicate the mosquito from isolated areas. If applied on an adequate scale it should prove possible by their use to eliminate completely the mosquito from islands, such as Cyprus, Trinidad and Mauritius, without in any way affecting the beneficent insects. The financial cost would be comparatively small and negligible compared with the gain in health and efficiency of the inhabitants. The control in Continental areas affords greater difficulty, but the results obtained by Symes and his co-workers in British Guiana and Uganda have already indicated that the problem is not insoluble. In spite of certain views to the contrary, it seems to be proved that the internal and external spraying of the houses in towns and villages with suitable solutions of the insecticides, owing to their lethal and residual effect, does result in a pronounced fall in the mosquito count and this must inevitably result in a diminution in the risk of infection. It should not be forgotten that at the same time other transmitters of disease, flies, fleas, lice, will also be killed. It is essential that the various problems involved in the use of these insecticides should be vigorously attacked in a bold and imaginative manner. Simultaneously we should not overlook the possibilities of the prophylactic and curative uses of paludrine and other medicinals and of the insect repellants such as dimethyl phthalate. If the co-ordinated attack on malaria, which is now possible, meets with success, which I believe it will, life in the tropics will be revolutionised, and science will have made another notable contribution to colonial prosperity.

A problem of far greater complexity is involved in attempting the control of the tsetse fly, the transmitter of trypanosomiasis. Whilst we know that a partial measure of control does result from a clearing of the bush the method is far too laborious and expensive to be applied over the vast areas which are involved. We know also that the fly can be killed by insecticides if brought into contact with them, but we do not know how this can best be done. The evidence at present available suggests that a solution may be found in insecticidal smokes applied either directly from aeroplanes or by smoke bombs dropped from them, but much further research is required. We must be prepared to attack this problem on a scale commensurate with its magnitude and the cost will be heavy. We should be encouraged to undertake this, however, when we see the success achieved against that major agricultural pest, the locust, by the combined use of gammexane baits and dinitro-*o*-cresol.

I have attempted most inadequately to show the part which science can play in the development of our Colonies and in the improvement of the health and prosperity of their peoples. For the man of science the opportunities are great, equally great are his responsibilities. He will not fail if he receives from the administration the support to which he is entitled.

SECTION C.—GEOLOGY

GEOLOGY IN THE DEVELOPMENT OF THE COALFIELDS

ADDRESS BY

M. MACGREGOR, M.A., D.Sc., F.G.S.

PRESIDENT OF THE SECTION

WHEN, eight years ago, the last full meeting of the British Association was held in Dundee, only to be interrupted by the imminence of war, Professor H. H. Read, President of Section C, had chosen as the subject of his address 'Metamorphism and Igneous Action' At this resumed meeting in 1947 I am certainly not proposing to emulate that perilous descent to the lower regions where migmatites are made. The gates of gloomy Dis lie wide open but few there are who return unscathed. My journey is a much less hazardous one and my subject a humbler, more prosaic, and perhaps more tractable one. I propose to consider very briefly the place of geology in the development of the coalfields. Several reasons have led me to this choice of a subject. In the first place, it is the express wish of the Council of the Association that Sectional addresses and discussions should conform, as far as possible, with the main theme of *Swords into Ploughshares* and should deal with subjects of general, topical interest; in the second place, it is a subject which, we must all agree, is of particular and indeed urgent importance at the present time ; and, in the third place, it is a matter in which I have long been interested and on which the last word has certainly not been said.

I do not need to remind you that on the first of January of this year the momentous and irrevocable step was taken by which the coal industry (and certain ancillary undertakings) was transferred from private to public ownership, and its management vested in a National Coal Board with its various divisional and areal commands. The structure of this controlling hierarchy may alter, but the fundamental change to nationalisation is a permanent one. The coal-mining industry with all its manifold ramifications, with all its potentialities, and with all its capacity to quicken or retard the tempo of our whole economic life has become —may I say in the truest and deepest sense of the words ?—a National Trust. And it is as a National Trust that it should, and indeed must, be regarded by all. This change, with its far-reaching consequences to which no one can assign a limit, with its complexities and hazards which no one can as yet assess, will require vigilant and unsparing service from all concerned. If the industry is to prosper and coal production to be increased, those who are placed in charge of it must have the loyal support of everyone and the best scientific and technical assistance that the country can give. There is a good deal of loose and irrelevant thinking and misuse of words and statistics current at the present time. If the old order of things has gone, if private ownership of the coal and coal mines, with its competition and its own incentives to effort, has been replaced by a new order, then this new order must provide incentives on a new and higher scale of values. Otherwise the change was not worth making. A new world can only come from a new heart, and I for one would wish to be quite certain that the hoisting of flags at the collieries on the first of January last was regarded as the symbol of a nation-wide spiritual dedication to service.

I am in what follows to ask you to consider with me how geology—that is, geological principles, geological technique, and geological methods of approach—can best assist in the development of our coal resources and in their most effective and economic use. This is not an academic or debatable issue ; it is an urgent and vital one. It is certain that the coal industry is already under a great debt to geology and all of us could, I am sure, cite striking examples of that cardinal fact. It is equally certain that the debt might well have been much greater than it is. The fault for this, however, cannot be laid wholly at our door, but it will be our fault if we do not grasp the opportunities now offered in the new era that is opening out, opportunities not only for service to the country but also for the advancement of our science. Our

contacts with the coal industry are now more direct and simpler. There need be no reservations or inhibitions, and there are no conflicting or competing interests to be considered. The information from borings, shaft-sinkings, adits, underground mines, cross-cuts, etc., is now immediately available with a completeness that was not always possible before. Here I must, however, state as my considered opinion that the advantages that geological research can gain from the unified control of the industry will be largely lost if continuity of service in the coalfields is not immediately accepted as an essential feature of our work. Lincoln once said: 'I did not make events; events made me'; and it seems to me our duty to rise to the height of our responsibilities in the events of to-day and in the circumstances in which we find ourselves.

The complexities and hazards which the unified coal industry has to solve and overcome are many, and the problems it has to face are never-ending. There are the manifold geological problems connected with occurrence, distribution, structure, and correlation; with vertical and lateral variations in the number, thickness and character of the seams, in the lithology and in the fossil content; problems connected with the size and direction of faults, the amplitude and pitch of folds, the occurrence of intrusions or suites of contemporaneous igneous rocks, the presence of wash-outs, rolls, buried river-channels, etc. It has been sometimes said that we are here invading the province of the mining engineer. That, however, is just plain nonsense. It is co-operation, with one end in view, that is required. I never yet met a mining engineer or responsible colliery official who was not only ready but anxious to discuss his difficulties and to have them reviewed from a fresh angle, or who was not at least easily persuaded to the advantages of this course. There are, again, the problems connected with the actual mining of the coals; there are the chemical and physico-chemical problems connected with their origin, composition and classification; and there are, too, the further problems that arise in relation to their preparation for the market and their economic use. All these fields of activity and research overlap to some degree, but all are essential in any scheme for conjoint and directed research. They require, however, to be much more closely integrated than they have been in the past, and the present time provides an opportunity to do this that may never recur.

The fact that the geologist is the first link in this chain of concerted effort is too often apt to be overlooked or forgotten in the assessment of the final results. There are, it seems to me, several reasons for this, and perhaps the main one is that we do not follow up our results sufficiently closely and persistently. A second reason, in my opinion, is that geologists, when dealing with economic problems, are sometimes apt to forget that the geological is only one aspect of what may be a many-sided question. I should like to say a little under these two headings, taking the second one first. It would be quite possible, although perhaps somewhat injudicious, to give recent examples to illustrate what I mean, and I prefer to choose one of an earlier vintage. In that very valuable inquiry into the Coal Resources of the World made on the initiative of the Executive Committee of the Twelfth International Geological Congress (3 volumes and atlas of maps, Toronto, 1913) the figure of estimated world resources allows of a life of some 5,000 years taking the 1913 output of the principal producing countries as a basis for computation. I must say that these estimates, which have often been reproduced in text-books, etc., and so gained a wide publicity, did nothing to warm me during last winter's cold spell when my ration of coal, forty per cent. non-combustible, sixty per cent. reluctantly calorific, was late in arriving. I did, however, try to find out the basis of these seemingly optimistic estimates, though with no great success. For example, in the summary tables prefixed to the first volume of this work, Canada is credited with 414,804 million metric tons of 'actual reserves,' including 675 million tons of anthracite, but no reserves under this category[1] are assigned to the U.S.A. Under the heading of 'probable reserves,' the figures for U.S.A. and Canada are respectively 3,838,657 million tons (including Alaska and 'coal deeply buried'), and 819,465 million tons. The position here is completely reversed, but still when we find all the 'actual reserves' in North America listed under Canada we begin to wonder just how far statistics of this kind take us. Further, the U.S.A. coals occur in the Upper Carboniferous, Cretaceous and Tertiary formations[2] in approximately equal proportions, while the approximate figures for Canada are: Carboniferous 0·6 per cent.; Cretaceous 95·1 per cent.; and Tertiary 4·3 per cent. By far the greater part of the Canadian resources of Cretaceous coal, again, is assigned to Alberta, the figures given being:—actual reserves: 386,373 million

[1] 'Actual reserves' are defined as including (a) seams of 1 foot or over, to a depth of 4,000 feet, (b) seams 2 feet and over at depths between 4,000 and 6,000 feet; the calculations being based on actual thickness and extent. 'Probable reserves' are defined as approximate estimates under the same two headings.

[2] There is a little coal in the Lower Carboniferous, in the Permian and in the Jurassic.

tons; and probable reserves: 649,833. These coals range in age from Lower Cretaceous (Kootenai Series), to Upper Cretaceous (Belly River Series) and late-Upper Cretaceous (Edmonton or Laramie Series). In 1945, however, in a *Report on the Coal Resources and Coal Industry of Alberta in relation to those of Canada*, the reserves of this province have been reduced to 46,562 million short tons of immediately available coal, i.e. in seams of three feet or more in thickness and within 1,000 feet of the surface. These resources are distributed as follows :—

In the Edmonton Series . .	5,219
In the Edmonton and Belly River Series	9,080
In the Belly River Series . .	2,563
In the Kootenai Series . .	29,700
Total (millions of tons)	46,562

Mr. C. A. Carlow, in a recent communication to the American Institute of Mining and Metallurgical Engineers, has also drawn attention to the anomalies in the 1913 figures of reserves and to the widely different estimates that have been made in later years for different countries, and has, rightly I think, suggested that the whole problem of world coal resources requires re-examination on a new basis, which should take into account other factors in addition to geological distribution. A summation of reserves or resources based on data of widely different validity is certainly not helpful and may well be misleading. Categories such as ' actual ' and ' probable ' are not distinct or descriptive enough and lend themselves too much to subjective interpretation. The essential factors from the geological point of view in assessing an area of coal-bearing rocks are : (1) age and geological history ; and (2) occurrence, distribution and character of the coals. The first set of factors conditions the second and it is the problem of geological history that seems to me the most important of all. The more we know, for example, about the geological history of our Carboniferous rocks, about the conditions under which they were formed, about the factors which controlled the sedimentation and gave it its rhythmic character, about the changing geographic and climatic surroundings, and about the various earth-movements and tectonic stresses that have affected them in later periods, the more complete and useful will be our contribution to the economic development of our resources. Particularly is this true in the case of the deeper and less accessible reserves still to be worked, where the knowledge we have already gained in the explored fields may well be of permanent value in guiding the new undertakings of the future. I must, however, add that the knowledge and experience necessary for this can only be obtained by a close, continuous study of the detailed geology of the coalfields, and of the earth-stresses to which they have been subjected. The more that is known about the relative ages of the various foldings, fault systems, and intrusions, and of their direction and extent, the more secure are the data available for use in any suggested interpretation of the structure of new ground.

This brings me to the second point I would like to emphasise, namely, that we do not follow up the results we get sufficiently closely and persistently ; but before going on to say a little on this matter I should like to return for a few minutes to the question of estimating and comparing reserves in general. There are, I imagine, three main categories under which these fall :—

1. *Proved*
   (*a*) by existing underground developments;
   (*b*) by borings.
2. *Partly Proved*
   (*a*) by borings ;
   (*b*) on geological evidence.
3. *Inferred :* i.e. where there is no direct, valid evidence as to the actual occurrence of workable seams.

Figures should only be given for categories 1 and 2 and should not be combined in any summary table ; while for category 3 general statements, such as ' probably considerable ' or ' possibly large ' would seem to be enough. At any rate I cannot but think that the 1913 figures give in many cases an erroneous impression, and the reason would seem to be that coalfields widely differing in age and geological history, in the degree of information available concerning them, in accessibility to world markets, and in the quality of their coals, have been treated, at least in the summary tables, as on the same footing. In the case of our own British coalfields we require a careful separation into proved, partly proved and inferred fields, and to pass from the one category to the other demands experience in the close scrutiny of all available data. There is no short cut to this end. It cannot be attained by periodic efforts or a discontinuous service.

If the geologist is the first link in the chain of technical service applied to coalfield problems, the links being the geologist, the mining engineer, the colliery manager, the chemist, and the fuel expert, his service and advice must be available at all times. I have pleaded this point of view often during the last twenty or so years and I am more than ever convinced to-day of its importance and indeed of its urgency. Continuous service

on the geological aspects of coalfield problems is essential in view of the issues at stake. Is this not, after all, simply carrying out more thoroughly and systematically duties that have already been assumed in part? There should be now no qualification or reservation as regards the scope of our work in this connection; the only criterion is the gravity of the position in which we find ourselves. Coal production must be maintained and increased, and accordingly developmental schemes will require to be carefully planned and considered from all angles if the most economic and effective results are to be secured. This applies both to short-term and long-term developments alike, and the geologist ought to be ready to apply the results of his experience in, and his study of, coalfield structures and sequences to the new extensions or new fields to be opened out. If there is any one who imagines that this type of work can be done at irregular intervals, taken up for a time and then discontinued, I can only say that I profoundly disagree, and in the next section of my address I should like to examine my own point of view more closely. By way of introducing this section I might say that I have written or compiled two accounts of the Scottish Carboniferous rocks, separated by an interval of some fifteen years, and I am only too well aware of the many gaps in our knowledge that still require to be filled and the many problems that still await solution. There is, for example, a wide field for research open in the study of the Carboniferous sediments, their detailed lithology, variations, sequences and rhythms, their relations to pre-Carboniferous or early-Carboniferous structures, and their mineralogical composition and mechanical constitution; and in the problems associated with their compaction and resistance to stress. All these have, in different ways, economic repercussions. A knowledge of lithological sequences and rhythms again is essential for detailed correlation work and indeed provides the most useful and often the only criteria available for the purpose.

If geology is to play its full part in the development of the coalfields, it must be prepared to render assistance along three main lines:—

1. It must be ready to advise on geological difficulties and problems as they arise in the actual working of the coals, and to make suggestions for overcoming them. From my own experience I might cite such examples as the significance of changes in dip and level course; the amplitude and direction of folds; the size, inclination and direction of faults; the thickness, character and mode of occurrence of intrusions; the variation trends in the thickness of the coals and the associated sediments; the origin and probable extent of barren areas; and so on. To meet questions on these and other problems implies an intensive study of the geology of the whole field and, so far as this is possible, of its geological history.

2. The geologist must also be ready to advise on development plans involving an extension of existing workings into fresh ground. Here, again, the same general types of problem arise and a structure has to be worked out based on such direct and indirect evidence as may be available. The results, though necessarily often incomplete and tentative, are extremely valuable in planning developments and in helping to ensure that these developments are carried out most advantageously and expeditiously.

3. In the third place the geologist must be ready to apply the results of his detailed work on the lithology, sequences, structure and palæontology of the explored or partly explored fields to the investigation of new ground or concealed areas of potential value. This demands a knowledge not only of the Carboniferous rocks but also of their general distribution and variations in thickness and coal content and of their geological history. He must be ready, by drawing on his stores of experience, to make suggestions as to the limits and structures of such fields and he will be able to advise as to the siting and probable depth of test-bores.

These three types of investigation must be regarded as stages of a continuous and continuing advisory scheme. I might mention a dozen or more problems in the Carboniferous of Scotland alone that are awaiting investigation, problems not only with important economic bearings but of great value to the advancement of geological knowledge. But an attack on them certainly requires considerable experience in coalfield work and in local problems. It is quite easy to misread borings and so reach wrong conclusions as to structure and these, if acted upon, may prove extremely costly in the long run. Experience and continuous service are essential if the best results are to be got and if both the economic and scientific problems are to be resolutely tackled. I have no doubt whatever on this point; nor have I any doubt but that the value of the advice and assistance given to the industry in the past has more than repaid the cost incurred in supplying it. I want, however, to see our advice and assistance become even more useful and authoritative in the difficult times ahead. And, still more, I want this advice and assistance given by geologists trained and experienced in coalfield geology and in coalfield problems. Sequences and correlations must be as accurate and exact as possible and

structures worked out as carefully as all the available data, whether direct or indirect, will allow. These are not easy tasks if carried out thoroughly, but on the results may depend important issues to economic development. Mistakes are certain to be made—it would be better to say that deductions are certain to be drawn which are later proved to be wrong—, and sometimes Nature plays unexpected tricks. A few weeks ago a boring was put down to prove two seams lying some 360 feet apart. The position of the upper one was occupied by the deposits of a deep pre-Glacial river-channel, the lower one was destroyed by a thick intrusion of dolerite. When both Pluto and Neptune enter the lists against us, there is nothing one can do about it ; *magna est veritas et praevalet.*

The results of a survey of a coalfield area must of course be expressed in maps, diagrams, sections, and descriptive accounts. Of the value of the six-inch maps to the mining industry there is no question. They provide an interpretation of the structure based on a consideration of all known data and focus attention on essential features. If, however, their usefulness is to be maintained, they must be brought and kept up to date, and it has not, unfortunately, been possible to do this with any completeness or in any systematic way. Many are long since out of date in the sense that they do not show the new information that has been collected in the course of recent years. There are, of course, perfectly valid reasons why this is so, but I am not, at the moment at least, concerned with this aspect of the question. What I wish to stress is the fact that the latest information and the latest interpretation are too often not available in the necessary format. There is a large body of geological data of all kinds obtained from borings put down within the last twenty or so years as well as from underground developments which does not appear on any published map. Every series of borings, every underground development adds to our knowledge of the detailed succession and structure, and requires to be immediately considered and collated with what is already known. It is not enough to examine a boring, name the seams and key-horizons, decide whether it provides a full sequence or cuts a fault, etc. The results ought to be studied in relation to the whole body of information already available and, wherever necessary, the old mapping altered accordingly. Unless this is done systematically we are simply recording data without weaving them into a geological pattern. I would be the last person to minimise in any way the value of the examination of borings from both the economic and scientific points of view and the first to insist that all core-borings should be inspected. But I feel very strongly that this is not enough and will certainly not be enough in the difficult years ahead. It is in this respect that I think we do not follow up our results sufficiently closely and persistently. Geological research should aim at leading and guiding developments in the coalfields, and I do not see how this can be adequately achieved unless we are prepared to place our considered views much more fully and certainly much more expeditiously in the hands of the mining industry.

Considering the delays and difficulties of printing and the shortage of labour and paper it seems to me that the necessarily long and elaborate process involved in preparing, engraving and printing six-inch maps of economic areas might well and with advantage be reviewed. I cannot see it meeting the urgent requirements of the present day. The old multiplicity of owners and interests has gone, and unified control will allow of concentration on areas or fields where immediate developments are projected. It should be possible to revise a six-inch sheet (or group of six-inch sheets), bring it (or them) up to date and then run off a number of copies. There are different ways of doing this, and the actual number of copies required, for, say, a group of four sheets, would be easily calculable and relatively small. By similar means diagrams and horizontal and vertical sections could be reproduced, and a short descriptive account of the area or field manifolded to the number required. These various documents could then be distributed at once to the centres where they are required. A signal advantage of such a method would be that any necessary corrections and/or additions could readily be made as developments proceed further or as fresh boring information becomes available, and could be incorporated on a series of new prints. Certainly in this way a full, up-to-date, and easily available record of progress in any particular field would be secured. This would be of the greatest value not only to the industry but also to the advancement of our knowledge of the Carboniferous formation. Certain corollaries follow naturally. For example, a much closer liaison with the developmental aspects of coalfield work would require to be maintained and full opportunity taken to follow these up from the geological standpoint. How much information of importance to the furthering of geological research has been lost in the past through lack of this liaison can only be surmised, but it is certainly very large. If it had been possible to examine borings, shafts and underground mines in the past in the same general systematic way as has been done

since the passing of the Mining Industry Act of 1926, much light would have been thrown on a wide range of stratigraphical and structural problems that still await solution. From all points of view a close liaison with the mining personnel would seem desirable and indeed, in my opinion, essential.

There are many difficulties as regards correlation, even in individual coalfields, still to be cleared up, and the nomenclature of seams is in itself too often a source of confusion and perplexity. This varying nomenclature, though often unnecessary, cannot in some cases be avoided. If anyone would provide a key to the seam by seam correlation of the coals in the Limestone Coal Groups on the two sides of the Central Coalfield of Scotland, and then carry this correlation northwards into the Firth of Forth fields, it would be a big step forward. There are two ways in which this and other problems of a similar nature can most effectively be approached. The first is by the close comparison of lithological sequences, rhythms and variations and the second is by the study of the factors that controlled sedimentation. Both methods are, of course, interrelated and depend for the validity of the conclusions drawn upon our knowledge of the tectonic history of early Carboniferous times. Progress in these directions does depend, however, on the continued collection and collation of all available evidence that can be obtained from mining developments, and it should never be forgotten that this evidence must be secured while the developments are in progress. This work may seem at the time somewhat tedious and indeed fruitless as regards immediately striking results, but of its ultimate value in helping to build up our knowledge of the stratigraphy, palæontology and physical geography of Carboniferous times there is surely no doubt. On the economic side, if I may return to it, such knowledge is often of fundamental importance: knowledge of the trends of variations in thickness and character of the stratigraphical units; knowledge of the relative ages of the different fold and fault systems, of the direction of the stresses which produced them and of their relation to episodes of igneous activity. The more we can learn about these the more solid and exact will be the assistance we can render in any assessment of the coal content, structure and accessibility of as yet unproved or partly-known fields. Geological research in the coalfields is not a series of separate *ad hoc* pieces of investigation but a continuous process by which, through the accretion of fresh data, a more and more broadly-based synthesis is built up.

The study of the Carboniferous sedimentary rocks is as yet only in its infancy. The lithological succession in the different fields is, generally speaking, well known, and detailed sequences, as I have already pointed out, provide the most useful key in close correlation problems. We possess a constantly increasing body of information regarding the detailed lithological and palæontological successions in different fields and make use of these as correlation-criteria. But there still remains much to be done as regards the study of the sedimentary rhythms and cycles in relation to the changing physiographic conditions of Carboniferous times. Further research in this direction seems to me to promise valuable results in inter-coalfield correlation problems. The important question of the application of modern petrographic methods to the study of our Carboniferous sedimentary rocks has not yet been seriously and systematically explored. There is as yet no adequate comparative account of these deposits, and no classification based on a systematic examination of their microscopic, chemical and physical characters. Such data are almost impossible to find in published form, though they do exist locally and incompletely in private hands. Terms like fireclay, shale, sandstone, etc., are still loosely used, and there is no adequate nomenclature or reference set of data to which new occurrences can be related.

I am merely mentioning these gaps in our knowledge as examples to illustrate my view that there is wide scope for continuous research on our Carboniferous rocks from both the scientific and ecomomic aspects. The many problems awaiting solution in the stratigraphical, structural and palæontological fields are interrelated and must be approached as such. I see no adequate way of doing this other than by an experienced personnel giving continuous and whole-time service in the coalfields. This work may indeed seem unspectacular and even tedious at times, but it is none the less essential for the dual purpose in view. We must take every opportunity of extending our knowledge of the Carboniferous rocks, and we must make our contribution to the economic needs of the country as effective as possible. This contribution must also be more direct, more immediate and more adequate than in the past. From my own experience, extending over many years, I am certain that immediate and first-hand knowledge of coalfield developments, that time and opportunity to study and assess the difficulties and problems that arise, and that close and continuous liaison with the mining industry are all necessary if geology is to take its right place in the forefront of our economic life. To ensure this means the assignment of at least

one trained and full-time geologist to each major coalfield or coalfield area. We cannot return to the conditions and outlook of pre-war times. I have already said that the unified mining industry must have the best scientific and technical assistance the country can give. This fact has been emphasised and underlined by the highest authorities, and so far as assistance from the geological side is concerned, it is for us to translate it into positive and immediate action. My two years of so-called retirement have only strengthened my conviction of the urgent need for a continuous and whole-time service on the coalfields. I am asking for a team trained in coalfield work to form an integral part of the Geological Survey service and to be assigned the task of carrying on and extending the work which the Survey, with its limited staff and multifarious duties, has not so far been able to complete. I am well aware of the difficulties involved, but I think too of the important rôle geology can play in the new era ahead of us. It is a rôle well worth playing and the stakes are high; and if my fairly long experience is any criterion it is a rôle of immense potential economic value.

I have merely tried in these somewhat discursive remarks to state some of the implications, as I see them, involved in the transference of the coal and coal mines from private to public ownership. The next few years will be critical. Geology can help in many ways, in planning ahead, in suggestions for economic working, in interpreting structures, in reading doubtful successions, in correlations and in other ways. It might even provide a definition of the word coal sufficiently simple and explicit to be understood by those who at present extend it to include a variety of other rock types. Let us see that we give our help unreservedly and as our share in what I called earlier a National Trust. It would seem to me to be a matter that concerns the whole body of British geologists; the need is there and it must be met.

SECTION D.—ZOOLOGY

ZOOLOGISTS IN WAR AND PEACE

ADDRESS BY

DR. EDWARD HINDLE, F.R.S.

PRESIDENT OF THE SECTION

AN interval of eight years has elapsed since my predecessor in this office, Professor Ritchie, delivered his Presidential Address to Section D. We now meet again, in the same city, even in the same hall, but under entirely different conditions, for during these years profound social and economic changes have taken place affecting the lives of all of us. The changes have certainly not been all to the good, but there is one change all members of the British Association will welcome, the wider appreciation of the possibilities of natural science and its application to the many problems with which we are faced.

I am rather doubtful, however, whether the contributions of zoologists to our national life are sufficiently well known, for even among my colleagues I find many who are quite unfamiliar with many of these activities. Accordingly, and also in view of the somewhat exceptional circumstances of the present meeting, I propose to depart from the usual custom of describing one's own researches, and instead to refer to some of the work in which zoologists have been engaged during the past few years. There is some difficulty in deciding what to select; if one accepts as an indication of its scope the subjects which have to be dealt with by the Zoology Committee of the Royal Society, we find a greater number than in any other Committee, fourteen subjects being included, comprising agriculture, anatomy, anthropology, bacteriology, biochemistry, biophysics, cytology, ecology, ethnology, genetics, oceanography, palæozoology, parasitology, comparative physiology and psychology.

Zoologists in War

The direct applications of zoology in military science are strictly limited but mention may be made of one branch which played a not inconsiderable part during the war, namely the application of the principles of animal coloration known as camouflage. My predecessor in the Chair at Glasgow University, Sir John Graham Kerr, in a letter to the Admiralty, dated September 24, 1914, first indicated a practical method of diminishing the visibility of ships at a distance. This letter was circulated to the Fleet on November 10, 1914, but during the early part of the First World War the carrying out of instructions was not placed under the supervision of competent scientific experts, but left to the discretion of individual officers, with the result that many ships were lost unnecessarily. Fortunately the subject received increasing recognition between the wars, partly as a result of the work of one of our Sectional Secretaries, Dr. H. B. Cott, then on the staff of the Zoological Department at Glasgow, whose book *Adaptive Coloration in Animals*, summarises the basic principles of effective camouflage. His lectures at the General Staff College before the War introduced the subject to many senior officers, and during the War camouflage officers were attached to various Commands. Dr. Cott himself was in charge of the Camouflage School, M.E.F., and as you are doubtless aware, camouflage played an important part in the battle of El Alamein. Those of you who have seen the film 'Desert Victory' may remember the very efficient way in which the tanks were camouflaged.

Antifouling is another problem which occupied the attention of a team of zoologists and others, working at Millport under the direction of Professor J. Harris. The effect of fouling on the speed and efficiency of naval craft, especially its affect on speed, may play a deciding rôle in naval operations. Some idea of its importance may be gathered from the fact that after only six months at sea, fouling in certain types of naval craft may increase fuel consumption by as much as 50 per cent. The visibility of submarines from the air is also seriously increased by some kinds of diatomaceous fouling, and a method was developed of protecting submarines against this additional risk.

These are somewhat minor activities, however, compared with the contributions made by zoologists to the maintenance of our food supply during the war, without which it is very doubtful whether the country could have been adequately fed. As you are doubtless aware, at the outbreak of War, expert committees were set up to decide the most efficient way of providing each person with the requisite number of calories. In balancing the respective claims of animal and vegetable foods, attention had to be paid to such problems as convenience of transport since a large proportion of our food stocks had to be imported. This raised such questions as whether it was better economy to import animal feeding stuffs to maintain our stocks of animals, such as cattle, sheep, pigs and poultry, etc., or to reduce their numbers and import meat and eggs. The conversion of vegetable material into animal proteins is a very wasteful process from the point of view of actual food calories, but there is considerable variation in animals, fowls giving an exceptionally unfavourable ratio. As you will realise in planning food economy other factors have to be considered, for example, the necessity for certain articles of diet such as milk and fats, to name only two obvious requirements. It is somewhat outside the province of my subject to go into details of the very elaborate calculations required to decide the quantity and nature of our food imports, but very early on the necessity for more efficient protection of our food stocks against animal pests began to be realised.

At the beginning of the War there was virtually no organised rodent control, except for a few efficient county councils which were doing good work, often with out-of-date methods. Fortunately the Bureau of Animal Population at Oxford University had been studying the problem for some years under the direction of Mr. C. Elton, and, in September 1939, started a scientific advisory service and furnished reports on rodent control to the Agricultural Research Council and other Government departments.

The first problem to be tackled was rabbit control, as this animal is a major pest on all developed land. The subject was discussed in a paper read before this Association in 1937 by Major C. W. Hume, Chairman of the Universities Federation of Animal Welfare, who gave some facts and figures relating to the wild rabbit problem. It is estimated that four and a half rabbits consume as much pasture as one sheep, and since the number of rabbits trapped annually in Britain may reach 36 million their effect on our agriculture will readily be understood. Trapping campaigns followed by cyanide poisoning of the burrows was found to be the most effective method, the correct dose of cyanide powder being introduced into the burrows by means of a long spoon. The burrows were then sealed in order to obtain the maximum efficiency of the gas liberated from the powder. Moreover, as a result of the great demand for more agricultural land, many warrens were ploughed up, so that complete extermination became a practical proposition on ordinary farmlands.

Rat control was also of vital importance, since an average brown rat eats about an ounce of dry food a day, apart from what it spoils and wastes by contamination and by the gnawing of sacks and other containers. Some idea of their potentialities may be gathered from the fact that the rat population of this country has been estimated to vary between 10,000,000 and 100,000,000. Yet almost every week in the popular press one can see sarcastic comments on the employment of rodent officers at the exorbitant remuneration of £300 to £400 per annum.

Large food stores are expecially prone to the attacks of these pests, and the amount of damage they are capable of inflicting is almost incredible. In addition, they are notorious carriers of disease and in Britain harbour the parasites of at least three human infections—spirochætal jaundice, food poisoning and trichinosis. Abroad they are responsible for the spread of bubonic plague, and certain kinds of typhus.

Without going into technical details, it was found that rat control came down mainly to finding appropriate poisoning methods, but this involved numerous investigations. Many of the commercial products on the market proved to be very unreliable, and it became necessary to find a poison which was not only efficient but also capable of being obtained in large quantities at a standard toxicity. Zinc phosphide was found to be the most effective of the commoner poisons and was widely used throughout the War. Prebaiting for four or five days with plain food before putting down any poisoned food, was discovered to be the most satisfactory method of application, giving kills of 90 per cent. or more of the rat population where it was used. Baiting with plain food is also a good method of testing the efficiency of any method of control. Sometimes it is necessary to use a special sequence of poison baits for the avoidance of poison shyness on successive treatments, and in some situations it is necessary to use poison bait containers which can only be visited by rats. The practice of killing rats at threshing time was adopted on a national scale for the control of rats in corn-ricks.

Rather surprisingly house mice were found to be much more difficult to control. These

animals were shown to be extraordinarily abundant in corn-ricks and certain kinds of warehouses and shops. Various methods of trapping and poison baiting were developed, but with only partial success. For example, corn-ricks can be gassed with CO_2, but the method is tedious and expensive.

These and many other investigations were the subject of a series of pamphlets issued first by the Bureau of Animal Population but subsequently by the Infestation Division of the Ministry of Food. The former has been responsible for fundamental research on the subject and the Division for the translation of these researches into methods of practical control. Since the end of the War the responsibility for research in the field of rodent control has passed to the Infestation Division of the Ministry of Food and is being conducted by a small group of zoologists and technicians.

The Ministry of Food is directly responsible only for the actual operations of rat and mouse control in its own warehouses. Elsewhere the Local Government authorities are responsible, under the direction of that Ministry, for ensuring that suitable measures are adopted by occupiers of urban property. It should be noted, however, that the Ministry of Agriculture is responsible for the control of rats and mice on agricultural land and the Ministry of Health for control in ports, where rats brought from abroad in ships might bring in such diseases as bubonic plague.

The position of air ports is still somewhat anomalous, as at present the Local Government authorities are responsible for the application of quarantine regulations against the importation of potentially dangerous rodents, insects, etc. Aircraft are now a much more serious problem than ships, for, unless care is taken, rats infected with plague, and mosquitoes infected with malaria, yellow fever or other insect-borne diseases, might escape at landing grounds and start epidemics. I know of one instance in which two black rats entered a plane with the cargo at Karachi, but fortunately were seen by the passengers, so that the local authorities were notified of their presence when the plane came down in this country. But I am not at all confident that all local authorities are sufficiently aware of the potential dangers of animal pests that might be introduced in this manner.

The training of local authority staffs and those of the armed forces and industrial organisations in control methods was the responsibility of some sixteen instructors in rodent control—all University graduates. These instructors made field surveys of rodent populations, carried out experimental work in connexion with the development of new methods and acted as technical advisers, in addition to their instructional duties involving lectures to adult audiences.

A very important branch of the Infestation Division of the Ministry of Food is that dealing with the control of insect and mite pests. As in the case of rodent control, this branch developed largely out of work that had been carried on for many years in University laboratories, including a survey of the infestation of grain carried out in 1938–39 under the direction of Professor J. W. Munro at the Imperial College of Science. This survey was undertaken at the request of the Department of Scientific and Industrial Research and led to the formation of the Pest Infestation Laboratory of the D.S.I.R. as a permanent centre of research.

Before the war, however, industrial interests in the subject had been organised into a Standing Conference on the Pest Infestation of Produce, and under the Director of Infestation Control, Mr. McAuley Gracie, initiated the survey of 1938–39. The Infestation Division is primarily an executive organisation and, as in the case of work on rodent control, translates the results of the research carried out at this laboratory into practical methods. The research and field-work involved and the application of control methods has been carried out mainly by University trained biologists, principally those who have specialised in entomology.

During the war this organisation became of great importance, and it is very doubtful whether our food stores could have been maintained without its assistance. It will be obvious that the building up of large food stores including grain and similar products brought from all parts of the world, and their storage for long periods, provided conditions especially favourable to the development of insect pests or mites. These are often present to some degree, but under normal conditions the damage done by them is limited by the shorter period of storage. When food stores had to be maintained for years instead of weeks, this damage became a much more serious problem and I recall various stocks of food being condemned as unfit for human consumption when infestation had got beyond a certain limit.

The present staff of the entomological branch of this Division consists of some fifty-five inspectors, stationed in five groups based on the principal ports. Each of these inspectors is a graduate in biology, some with special training in economic entomology. The inspector determines the nature and degree of any infestation in foodstuffs and in the buildings, ships, etc., in which these foods are stored ; and also considers what development

of the infestation is likely to take place, taking into account the species of insect or mite present, the time of year, the nature of the commodity and the likely period of storage. The action necessary to prevent or minimise the development of the infestation and the measures to be adopted are reported to the control organisation for action. Finally, after action has been taken, the commodity or structure is again examined to ascertain the degree of success and to decide what further measures may be necessary.

During the period of development in 1942–43, it was possible to staff the organisation, especially the senior posts, with trained zoologists, including entomologists, and a few chemists, but the number was limited owing to the demands for biologists in other fields. The bulk of the inspectorate, therefore, came to be composed of newly qualified graduates, both men and women. They came with little or no knowledge of economic entomology, and therefore every recruit was given a short course covering general entomology, insect identification, methods of control and administrative organisation. It was found in practice that inspectors became efficient after some twelve months in the field.

During the war the staff of the organisation included among others an Assistant Professor of Zoology, a Reader in Applied Entomology, a cytologist, a freshwater biologist, a marine zoologist and a lecturer in entomology. Also as Honorary Inspectors, a Professor of Zoology and two lecturers in Zoology. At present a small cadre of the senior staff have received a full training in economic entomology, but the bulk of the inspectorate consists of war-time graduates. The development of the Division on a permanent peace-time basis will provide a new field of employment for zoologists.

In the autumn of 1941, before the organisation was established, there was a severe outbreak of the Cacao Moth, *Ephestia elutella*, in many of the reserve wheat stocks of this country. Since that date there has been no major outbreak of infestation and no appreciable quantity of stored food has had to be destroyed or diverted to other uses solely on account of infestation either by insects, mites, rats or mice. This has been achieved at a time when a high proportion of the imports were more heavily infected than usual, as a result of a variety of causes including long sea voyages, ships being held up in convoy and long periods of storage. As an extreme example of the length of some of these voyages, a Turkish ship containing dried fruits sailed from Constantinople whilst the passage of the Mediterranean was interrupted, went through the Suez Canal, down the East coast of Africa, round the Cape and across to South America. The ship then sailed up the coast to New York and from there across to this country, having twice crossed the equator and covered a distance greater than a journey round the world.

Port inspection now enables every food ship to be inspected on arrival and any infestation dealt with before distribution. Before the war the only commodity regularly fumigated on arrival in this country was Australian dried fruit; at present all dried fruit is fumigated on arrival and any other infected commodity can be treated if necessary.

A mass of interesting and significant information regarding the ecology of the rodent and insect pests of stored products has been acquired in the course of this work, and it is hoped that eventually this information will be analysed and published.

I have dealt at some length with the activities of the Infestation Division of the Ministry of Food, since it developed as a direct result of war conditions and was staffed largely by graduates in zoology.

Time prevents me from making more than a brief reference to the field of agricultural parasitology, in which valuable contributions were made in the control of parasites of crops and farm animals. The activities of the Fisheries Department of the Department of Agriculture and Fisheries have been dealt with in previous addresses, and I will only add that this Service maintained its high reputation. Reference may be made, however, to one or two investigations undertaken during the War with the object of increasing our food resources. The possibility of utilising the large swarms of marine plankton that occur periodically in our seas, especially off the west coast of Scotland, was examined by Professor Hardy and his colleagues, but its collection in quantity was found impracticable owing to technical difficulties.

The use of unmarketable fish, however, was successfully developed by Dr. L. Harrison Matthews in the Bristol Channel, and would seem to offer good prospects in regions where a wide tide range makes possible the use of various fixed engines for fishing. In the upper part of the Bristol Channel these devices are fixed to the foreshore and include basketwork traps whose design is of great antiquity, and different kinds of stake nets. The fish are brought to them by the tide and the catches include cod, whiting, various species of flat-fish, rays, conger, and other species in smaller numbers. In the summer, shrimps constitute the most important part of the catch, whilst in winter their place is taken by sprats. The catch includes large quantities of fish of unmarketable size, and until 1939 the weight of this 'rubbish'

frequently exceeded that of the marketable catch landed.

When, in 1939, the waste of potential food was particularly undesirable, the manufacturers of fish products were approached to see if they could utilise the fish that was being discarded. It was found that if the unmarketable fish were cooked in superheated steam at 120° C. for ten to twenty minutes, the bones, scales and rays were softened and the cooked product could be ground up with other ingredients to make an excellent fish paste. About one and a half tons a week of fish formerly wasted was thus made available for human consumption and the industry could be extended to other parts of the coast.

Dr. Worthington, at the Freshwater Biological Station, Windermere, developed a war-time industry to enable the utilisation of the large numbers of perch occurring in the Lake. Tinned perch was put on the market and added a little to the country's food supply, but in normal times these could not compete successfully with sardines and other marine fish.

Experiments on the possibility of raising the fertility of a given area of the sea by the addition of nitrates and phosphates were carried out at Loch Sween (Argyll) by Dr. Gross in collaboration with other members of the Department of Zoology of the University of Edinburgh, and the staff of the Scottish Marine Biological Association, Millport, with the assistance of the Imperial Chemical Industries. The results clearly indicate that the application of fertilisers in a shallow loch and also in an open arm of the sea was followed by an increase in the phytoplankton, reaching at times densities never previously recorded. This was followed by a corresponding increase in zooplankton, and then there was a marked acceleration in the growth especially of bottom-feeding fish, plaice attaining at the end of their first year a weight five times greater than on normal grounds.

The prevention of disease, especially those infections transmitted by biting flies, is always of vital importance in any military operations, and during the recent war, the casualties from malaria and other insect-borne diseases on certain fronts far exceeded those caused by the enemy. In Burma, for example, in the early part of the war, malaria caused nearly half the total sickness ; and in the Nile Valley, Upper Egypt, during 1943, some 130,000 people died of malaria carried by *Anopheles gambiæ*. During the war a number of entomological units usually officered by zoologists, were created and sent to various parts of the world to study mosquito control and other local problems necessary to protect our troops from such diseases as malaria, typhus, scrub typhus, relapsing fever, etc. The introduction of efficient insecticides, which forms the subject of our joint discussion with the Sections of Chemistry and Agriculture this morning, contributed very largely to the success of their efforts, and, as you are probably aware, typhus epidemics were completely arrested in Italy and North Africa by the use of D.D.T. The prevention of malaria was largely the result of using prophylactic drugs such as mepacrine (atebrin), but mosquito control, especially in the neighbourhood of large permanent camps or aerodromes, helped to reduce the risk of infection, not only from malaria but also other mosquito-borne diseases such as dengue, yellow fever, filariasis, etc.

Malaria, however, still holds its place as one of the most important diseases in the world, though notable advances have been made in its treatment and also in our knowledge of the mosquitoes responsible for its transmission.

It is difficult to assess the activities of zoologists in this field, for much of their work comes under the general term of ' medical research.' It is too often overlooked that this term includes the work of a large number of investigators without medical qualifications, who merely happen to have become engaged on scientific problems having medical (or veterinary) applications.

But the contributions of zoologists to the war effort have ranged far outside the confines of their subject for their training was found to be an excellent foundation for the study of various military problems ranging from statistical investigations on the most efficient methods of bombing and the interpretation of the results, to the development of radar, meteorology, and even the possibilities of psychological warfare. At least sixty zoologists ranging from University professors to junior assistants were commissioned to various arms of the Services, many being engaged on operational researches of the highest importance. Much of this work is still of a very confidential nature, but I am at liberty to refer to one example, the practical development of radar, especially in connexion with gun-laying devices for anti-aircraft guns, which was very largely the work of a team including a number of zoologists among others L. Harrison Matthews, David Lack, G. C. Varley, H. G. Callan, and H. D. Slack, who went out to the A.-A. gun-sites and helped to maintain radar during the early attacks in 1940. Later R.E.M.E. was formed and carried out these duties, but most of the zoologists were invited to join operational research groups in different arms of the Service. When the

Air Council in 1942 decided on the development of a promising device called 'H_2S,' one of these teams investigated the apparatus, and when it was being produced in quantity in December 1942, at once tested the sets and helped to make them operate. They also personally installed them in the first two squadrons of aircraft. The original gear refused to work, but, by the middle of January 1943, various modifications had been developed and several aircraft had been equipped and were ready for trial by the R.A.F. Meanwhile radar schools were established to train the necessary mechanics. Eventually nearly all the aircraft in Bomber Command were equipped with radar, and some of the original staff fitted radar in the aircraft of Coastal Command and trained the operators. As a result enemy submarines were brought under control in the spring and early summer of 1943, and did not become a serious menace again until the invention of the 'Schnorkel' in 1945. The radar device H_2S was also adapted to Navy rocket ships and first used in the invasion of Sicily, with such success that it was used on a large scale in the Normandy landings on D-day. Radar units were also attached to American aircraft, and the headquarters of these units were always with the Pathfinders, the most important users of this invaluable device for finding targets.

One of the great difficulties of radar is that, unlike wireless, when a set is switched on it does not always work automatically, but seems to be extremely temperamental and often gives unexpected results. Zoologists proved to be particularly well fitted to cope with these difficulties, since by their training they become accustomed to handling large numbers of uncontrollable variables. The part they played in 'providing the tools' has received very little public recognition, yet the practical application of radar was one of the deciding factors in the War. There was certainly some justification for the selection of an academic zoologist as the central figure of that somewhat melodramatic film 'The School for Secrets.'

Zoologists in Peace

I have already referred to the development of the Infestation Division of the Ministry of Food with its Pest Infestation Laboratory as a permanent centre of research. These activities may be expected to continue and help to check the serious losses in our stored products. The annual depredations caused by rodents, insects and mites are difficult to estimate in exact figures, but are certainly out of all proportion to the somewhat limited expenditure on their control. The late Dr. L. O. Howard, a well-known authority, some years ago estimated the loss to the U.S.A. from insect pests alone at about 2,000,000,000 dollars a year. Dr. S. A. Neave, whilst Director of the Imperial Bureau of Entomology, summarised data relating to economic entomology in the British Empire, and considered that 10 per cent. was a conservative figure at which the losses due to agricultural pests might be placed ; in other words, not less than one-tenth of the human effort in agriculture alone was being dissipated by our insect enemies. The loss of grain in India due to rodents, insects and moulds has been investigated recently and estimated to amount to at least 12 to 15 per cent. You will realise what this means when a saving of 10 per cent. of that loss would be sufficient to prevent a famine diet. In the case of insects that transmit disease, it is impracticable to represent losses in figures except perhaps where domestic animals are concerned. It is probable, however, that the losses by death and ill health arising from insect-borne diseases are even greater than those caused by agricultural pests.

Some years ago Dr. Neave made an interesting comparison between the expenditure of the British Empire on Economic Entomology and that of the United States of America. At that time the total Revenue of the British Empire reached the sum of £1,400,000,000 per annum and the expenditure on entomology was about £500,000. In the U.S.A. the corresponding figures were £800,000,000 and £2,000,000. In other words, the U.S.A. was expending proportionately nearly seven times as much money on this subject as the British Empire.

Comparable figures since the War are not yet available, but I am reliably informed that the number of entomological posts has not changed substantially and is quite inadequate to deal with the many problems throughout the Empire. Among these I may mention the control of tsetse flies, which prevent the agricultural development of large tracts of Africa.

As for ordinary agricultural pests, great changes are about to take place in Africa as a result of the Colonial Development schemes. The welcome announcements by the Secretary of State for the Colonies that our African Colonies and Protectorates are being called on to contribute to food production on a grand scale, emphasise the high importance of the protection of the crops, both while growing and after harvesting, from the ravages of insect pests. It is doubtful if the potential menace of these insect pests has been adequately assessed or provided for. The first scheme for large-scale food production in Africa concerned ground-nuts or monkey-nuts (*Arachis*), mainly as a source of oils and

fats, and the chief territories chosen were Northern Rhodesia in Central Africa and the East African territories of Kenya and Tanganyika. In the provisions of the scheme, emphasis is laid on the tsetse flies as a likely source of trouble, and the appointment of an entomologist for work on that problem is proposed. There are, however, at least two other entomological problems which will almost certainly acquire serious importance as the planting scheme extends. One of these, the danger of the virus disease of ground-nuts, commonly known as 'Rosette' disease, conveyed by the greenfly *Aphis laburni*, is referred to in the scheme; the other, namely the destruction of nuts after harvesting by Bruchid weevils and Phycitid moths, has not been assessed.

These two potential sources of danger deserve more serious consideration. It is almost axiomatic in agriculture that when a single species of crop plant is grown as a pure crop over extensive and continuous areas, the insects feeding on that species are immediately favoured, and, unless checked, build up populations which periodically attain such dimensions as to be uncontrollable. It is much to be hoped that before planting is begun on a large scale this danger will be anticipated. If it is, and if adequate preparations are made to meet it, the danger may be overcome.

If, on the one hand, mechanised cultivation and handling of a single crop over large areas brings its special entomological risks, on the other hand, it may well prove that this same mechanised agriculture, by permitting the organised use of mechanised control of pests by insecticides, may reduce once and for all time one of the most serious handicaps in tropical agriculture. The place of insecticides in agriculture is being discussed at our joint meeting this morning; meanwhile, I feel it is important to call attention to it with particular reference to the proposed schemes for food production on a scale hitherto undreamt of in tropical agriculture.

Locusts are among the most spectacular of pests and their ravages have been famous since biblical times. A special bureau has now been created to deal with their control, and it seems probable that the knowledge of their breeding habits and general ecology, which has gradually been acquired, is being applied with a certain measure of success, as I notice from a recent report that for the first time in many years no swarms have been recorded in Kenya during the past year.

Before leaving this subject, reference should be made to the Imperial Institute of Entomology, which came into existence in 1913, and remains the main centre for the collection and co-ordination of all information bearing upon injurious or useful insects and for the dissemination of such information throughout the world.

The permanent staff of this Institute is about thirty, of whom one-third are qualified entomologists. Their publications include the 'Review of Applied Entomology' which is published monthly in two separate Series, A, dealing mainly with agricultural pests and those of stored products, and B, with Arthropods of medical and veterinary interest. These two series comprise abstracts of the world literature in all languages on economic entomology and allied subjects, papers in unfamiliar languages or somewhat inaccessible publications being abstracted in relatively more detail.

Among other publications they also prepare the Insecta Part of the 'Zoological Record' on behalf of the Zoological Society of London. Collections of insects are sent to the Institute from all parts of the world for identification, this work being done by the Institute staff in co-operation with specialists on the staff of the British Museum (Natural History) and other authorities overseas.

Perhaps I may seem to have devoted an undue proportion of my address to entomology, but I would remind you that Insects outnumber all other free-living terrestrial animals put together, and about three-quarters of all the described species of animals belong to this Class, with literature in accordance with such a vast subject. I emphasise free-living animals for, in my opinion, they must be far outnumbered by the number of species of parasitic animals.

I now turn to Taxonomy, a most important branch of zoology which will form the subject of one of our Sessions. The necessity for the accurate identification of species has never been greater, partly as a result of the increased interest in ecology and genetics, and also because of the larger numbers of animals recognised as of economic importance. Unfortunately, increasing demands have gone hand-in-hand with a diminishing supply, for nowadays the number of expert 'amateurs' prepared to undertake the identification of species is very much less, and for various reasons, mainly economic, not likely to increase, at least in the near future. The present staff of the Natural History Museum is quite inadequate to meet all these demands, in addition to their duties of maintaining the national collections and arranging exhibitions of natural history in the public galleries. Various proposals have been put forward to deal with the problem, and the Linnean Society of London has recommended the creation of an Empire Biological Service in which taxonomic work would be one of its essential functions. Without going into

details, it is suggested that candidates for this service should be honours graduates in zoology (or botany), and after admission should serve a probationary period of at least two years during which the officer would be attached for training to one of the leading taxonomic institutions. It is also considered highly desirable that the officer should have the opportunity of doing field-work not only in this country but also overseas in any region offering more favourable conditions for the study of any particular group. Such a Service might provide a pool of taxonomic specialists, who could be attached, not only to national and provincial museums in Britain, but also to corresponding institutions in the British Empire. They would also be available for any special biological investigations or expeditions requiring the services of a taxonomist.

I have only had time to mention a few selected activities with obvious economic applications in our national life, but I should be very sorry to leave you with the erroneous impression that these constitute anything like the whole of zoology. Nearly all these various activities ultimately depend on the zoological departments of our Universities and University colleges, which are responsible for the basic training and to some extent the mental outlook of our graduates. Personally, I am strongly of the opinion that an academic zoological training has an educational value out of all proportion to its economic possibilities, and that a very great responsibility rests on the heads of zoological departments. I have the impression that in some Universities a disproportionate amount of time is devoted to particular aspects of the subject with the result that the student's training is somewhat lop-sided. For example, comparative anatomy, the very framework on which many of its activities ultimately depend, has been neglected by zoologists to such an extent that it has not been possible to fill an anatomical research fellowship founded by the Zoological Society of London. Yet any one trained in the methods of comparative anatomy, as shown in the war, is able to turn his hand with success to most things.

I stress the educational value of a zoological training especially since the number of openings for professional zoologists, even with the present greater demand in such directions as entomology and fisheries, is strictly limited and in normal times not likely to be more than something of the order of fifty a year. But as a general educational subject in schools it might well take a more prominent place. In this connexion I have been much impressed by the address of Professor Raven, Master of Christ's College, entitled 'Religion and Science,' delivered last year. He aptly points out that in the great days of the 17th century when this country rose to its highest level of intellectual achievement, scientists and theologians began to discover the joy that artists had always known, the delight in nature for its own sake. The scientific movement of that time, in which the foundation of the Royal Society in 1662 is a crucial point, was predominantly biological. It was the study of life, the work of zoologists and botanists, physiologists and medical men, that gave its driving power to the Royal Society in its first half century. Even Boyle's work on chemistry and physics was very largely concerned with organic studies. By the end of the century Newton's great prestige led to a concentration upon mathematics and the acceptance of the Cartesian doctrine that science is concerned solely with the material, with weight and measurement, and the mechanism of our animal nature. The effect of this on the Royal Society is shown by the remark of Ray's brilliant follower, Walter Moyle, who after many years retirement, revisited the Society in 1716 and reported sadly 'There is now no room for natural philosophy at Gresham's College; mathematics has engrossed all.'

To-day, the original meaning of *natural* philosophy seems to have been almost forgotten, and the holders of chairs which still retain this ancient title are now concerned entirely with physics or mathematics. Surely the time is ripe for a return to a less mechanistic training of the younger generation, by devoting more attention to the cultivation of a sense of admiration for the beautiful in Nature, and to a realisation that they must regard themselves as part of the total ecology, and with that in view to study the facts of life. If these are intelligently studied, men will be less ready to attempt to run human affairs on the lines of false ideologies quite incompatible with the present state of our imperfect knowledge of human behaviour. Moreover, in the light of the study of living beings, they would develop a humility which is the beginning of all wisdom, and I think a mutual tolerance which is the best antidote to War and to internecine strife.

SECTION E.—GEOGRAPHY

GEOGRAPHY IN WAR AND PEACE

ADDRESS BY

PROF. E. G. R. TAYLOR

PRESIDENT OF THE SECTION

AND what have they done? What have they done?' This was the question derisively asked by the educated public about the Fellows of the Royal Society in the early years of their incorporation. It is asked to-day, and in the same mocking spirit, about geographers. But before I answer it by sketching in outline some of the geographical work done in war time, and other such work in progress now that we have peace, I think it is worth while to quote from the reply which was made by the Rev. Joseph Glanvill, Rector of Bath, to those Aristotelian scoffers at the New Science in the 17th century. 'What one Age can do (he wrote) in so immense an undertaking [for to arrive at a "true knowledge of General Nature" was the original objective of the Royal Society], what one Age can do can be little more than to remove the Rubbish, lay in the Materials, and put things in order for the Building. . . . We must seek and gather, observe and examine, and lay up in Bank for the Ages that come after. . . . True knowledge (he added) must proceed slowly, by degrees almost insensible.' The same answer serves for the defence of any young science, and particularly for the young science of geography which seeks to collect, record and interrelate the myriad phenomena which produce the regional differentiation of the Earth's surface: with the ultimate purpose of evaluating such 'circumstances of place' in relation to human history and human affairs. That 'Geography and Chronology are the Sun and the Moon, the Right Eye and the Left of all History' was the bold yet familiar saying of the Elizabethan Age; and it remains true to-day that every historian, politician or philosopher will admit that circumstances of time and place are rarely irrelevant to the events or policies he is discussing. Yet each normally regards geographical circumstances as mere 'accidents,' and as being of so obvious a character that it needs no trained geographer to point them out: much less are they thought to deserve analysis in detail. The economic historian Professor Nef, for example, referring to the freedom of England from major wars during the troubled continental period of 1540–1640, expressed the opinion that geography was the principal reason for our century of peace. Yet by 'geography' he meant no more than that Britain was an island, and it is not necessary to look far to learn that mere insularity conveys no immunity, but rather that an island may become repeatedly a theatre of war. A military expert again, writing on the Balkan campaign, declared that its strategy was 'entirely a matter of geography.' True! but he understood by this no more than that owing to the very restricted corridors of movement there are certain key sites of vital importance—an analysis correct enough so far as it goes.

This over-simplified view of geography, which considers its content as obvious to any intelligent person, is that generally adopted by humanists to-day, and as a consequence not one of the new schemes put forward for the advancement of general education and culture, whether by means of university degrees designed to achieve a balance between science and the humanities (as in the plan put forward by the British Association), by the devotion of more money to research, or specifically by fostering the social sciences (as recently urged in the House of Lords)—not one of these contains any reference to geography. The pure scientist (although he plays a much smaller part than the humanist in educational policy and administration) also sees no reason to include geography in the curriculum since (except in certain limited aspects) it is not susceptible of study by the method of controlled experiment in the laboratory, and consequently (as he sees it) is neither a science nor a useful discipline. Nevertheless, wherever there are Geography Departments in the Universities these are full and overfull, while owing to this demand on the part of students, the number of Chairs in Geography has been rapidly

raised in the last few years. This has coincidentally created a real problem as regards competent teaching personnel, the more so as several of our most promising younger geographers have accepted invitations to take up posts in new Departments overseas.

The fact is that the consequences of the regional differentiation of the world's surface, or in simpler terms the circumstances of place, are beginning to be recognised by ordinary people as crucial factors in world affairs to-day, and it is imperative that geography in its widest modern sense should be accepted, not merely as an academic specialism, but as a necessary part of the habitual background of intelligent thinking. What are the primary facts behind the expression 'Great Powers'? They are geographical. Power depends first and foremost on the command of developed food-bases: that is to say of agricultural lowlands where the climate is an optimum for two or three of the more nourishing food-grains. Secondly, it resides in what I may term mobility and accessibility—a situation athwart those natural lines of movement by land and water which link current growing-points of world development. Thirdly, power implies the command of very large-scale mineral resources, and in particular (indeed of supreme importance to-day) command of major sources of mechanical power, coal and oil, supplemented by accessible large-scale concentrations of falling water. Now the patterns of world distribution of lowlands, of optimum climates, of natural accessibility, of particular minerals and power resources are all quite different and distinct. Hence the chances of a coincidence of the complete combination of advantageous conditions within the boundary of a Nation State are remote. Naturally the chances increase with size: but size alone, even of the order of millions of square miles, is not enough, although it allows the combination of the two opposites, accessibility and inaccessibility, the latter having its function in modern warfare. Since the days have passed in which these prerequisites of power could be assembled under one flag by overseas Empire-building, two countries only, by no intrinsic merits of their own, qualify as First Class Powers. The precise assessment of the geographies of the United States and the Union of Soviet Socialist Republics becomes, I submit, as important as the precise understanding of their ideologies. Are they closely matched? Or (from the theoretical standpoint) could a better balance be obtained if by means of some alliance Canada were thrown into the scales on the one hand and contiguous parts of the Middle East on the other. This would level up mineral oil, timber and gold, but would create new disparities in certain very desirable strategic metals and ores, and possibly in fertilisers, which lie behind food, which lies behind manpower. But if we lined the whole world up behind them in two chains, like children playing oranges and lemons, we could not achieve a perfect geographical balance. World unity is the only solution.

These inharmonious patterns of men and things which 'expansion' seeks to correct are not mere accidents, mere isolated facts or 'things in themselves.' The Earth, its resources and its living inhabitants form a related organic whole, not to be understood if merely regarded piecemeal. This concept of Geography, that it is the global way of examining and interpreting phenomena, was first sketched out by Alexander von Humboldt at the opening of the 19th century. And global thinking was never more needed than to-day. As Sir Halford Mackinder said in one of his last public pronouncements (and I quote him as a tribute also to his memory): 'Henceforward nothing significant can happen in human affairs at any spot on the earth but what its effects will spread, like the Krakatoan dust, over the whole global surface. We have now to adapt our minds to living in a closed environment.'

General Smuts has recently pursued the same idea in his Introduction to the late Professor Bews' *Human Ecology*. 'The world is not a chaos, [not] a chance selection of items and fragments. It is a closely interwoven system of patterns. . . . Our most painstaking effort at understanding the world discloses certain dominant features in it—rhythm, regularity, interconnexion and linkings up, an interplay of active relationships which is creative of structures, forms, patterns. . . . This is the holistic doctrine which underlies ecology. The organism is not itself alone and in isolation. As a unit it is a mere static abstraction. The real dynamic unit is the organism functioning in its environment.' Smuts was here ranging rather beyond the limits of geography, for human ecology extends further than the visible patterns of men and things upon the earth's surface, the cultural landscape as it is called. But the 'holistic' view-point is what we, too, seek to establish.

It is one of the unfortunate maladjustments of our time that the solution of problems by fragmentation, abstraction and isolation, absolutely essential as it is to the methodology of pure science, but involving a minute specialisation of knowledge and interest, has come to be thought of as desirable for its own sake, and indeed as providing a pattern for all organisations and systems necessary to the conduct of affairs. We see the results in the

rigid departmentalism at all levels of Government, of the Services, of the Schools and Universities, with the result of almost insuperable difficulties in securing co-ordinated action or of effecting ' combined operations.' While this way of thinking persists, geography is naturally under suspicion, since to speak of a geography ' specialist ' appears to be a contradiction in terms. The early results obtained, moreover, by this young science have been necessarily crude, but this fact certainly affords no logical reason for rejecting its objective—a grasp of the world as a functioning whole. The social sciences, to which geography is in many ways akin, have similarly wilted under a boycott by the pure scientist based on the like grounds : that they deal either with the obvious or with the imprecise. ' Voices are still raised (wrote Dr. Julian Huxley not many years ago) proclaiming that social science is a contradiction in terms, that current affairs are not intrinsically amenable to scientific method. Those who hold this opinion are, I believe, wrong. They are confusing the methods of natural science with scientific method in general. Social science differs inevitably from natural science in many important respects, notably in its lesser capacity for isolating problems, and more generally in its lesser degree of isolation from other aspects of human activity and its greater entanglement with problems of value. It must therefore work out its own technique and its own methodology, just as natural sciences had to do. . . .' A beginning has now been made of developing methods of sampling and of group investigation in sociology, where, as in geography, the impossibility of isolating a ' pure ' problem means that a number of diverse skills must be brought to bear upon it. But so thoroughly has the force of education and example indoctrinated us all with a belief in individual specialisation as the only road to success that the process of projecting and merging the individual mind into the group mind is found extraordinarily difficult. This is the more so since group work like team work requires careful planning, and mere mention of a planned investigation is at once construed into an attack upon scientific freedom. The rigid attitude hitherto taken up by the Royal Society as to what constitutes ' science ' has undoubtedly borne very hardly upon geography and sociology alike, although the term ' experimental philosophy ' was certainly not thus narrowly interpreted by the first Fellows, men like Bishop Wilkins, Robert Hooke, Sir William Petty and Edmund Halley, to judge by the actual papers they read to the Society. However, the situation is once more changing, and it is apposite to quote again from the words of the Society's advocate in 1668. The Rector of Bath expressed the opinion that ' Those that attend there (that is to say at the Royal Society's Rooms) never see the least inclination to any unhandsome opposition or uncivil reflexions, no bold obtrusions or confident sayings. The forbearing such Rudenesses is indeed a Law of that Society, and their Designs and Methods of Inquiry naturally form men into the modest Temper and secure them from the danger of the quarrelsome Genius.'

It is now possible to say that in spite of the imperfect methods and techniques and the almost negligible funds at their disposal, in spite, too, of their anomalous position between the arts and the scientists, geographers are convincing a slowly widening circle that a careful consideration of the circumstances of time and place and their differentiation from region to region, from one country to another, is of assistance in illuminating or solving their particular problems. Archæologists, historians, economists, biologists, as well as industrialists, agriculturalists, physical planners and members of the Services, have increasingly sought geographical information and advice, and made use of geographical literature. Indirectly one result has been to widen the field of employment of trained geographers, which in turn should lead to an intake of students of higher mental calibre than hitherto.

It is, however, true of all specialists, and not only those in the academic world, that however meticulous they may be in their own researches, however cautious their conclusions in their own field, they are yet impatient of the degree of specialism which they encounter in other branches of knowledge. Failing brief, clear-cut answers to complex questions, they skim the literature and come away with first approximations only. Examples of what I have in mind will occur to you all. The brilliant study of Prehistory entitled *The Personality of Britain* has a geographical basis which would gain immensely by refinement. A recent monograph on *The Location of Industry*, in which a valuable index of concentration is devised, is gravely marred by insufficient regional differentiation. In the erudite and far-ranging *Study of History* by Arnold Toynbee, again, the broader effects of the geographical environment are examined at considerable length. Yet the geographical reader cannot but be severely shaken when he finds, for example, a conclusion based on the assumption that the Jordan Valley, save in point of size, presents a similar environment to the valley of the Nile. The geographer, of course, is in constant danger of similar lapses, for he is almost always at work on the

borderline of some other specialism, and has often exposed himself to well-deserved censure. There is, however, a growing body of literature, upon Historical Geography for example, which has stood the test of criticism. Most of us have read the stimulating analysis of the loam-terrains of south-eastern England in their relation to early settlement, and mention may be made of a full-length study of the debatable frontier between Italy and Jugo-Slavia, and of several interesting papers on the belt of countries forming the so-called *glacis* abutting on Soviet Russia. A geographical study of the regions of Germany has had topical importance as has also a composite picture of the geographical background to the Palestinian problem presented by one of our colleagues who accompanied the Anglo-American Commission to that country. If Professor Chadwick's suggestion of regional studies of the history, culture and material environment of foreign peoples as a much needed part of the University curriculum bears fruit, geographical collaborators will not be to seek. In the physical field a monograph on the morphology of our coasts, contributions of great social value to our knowledge of microclimatology, and a survey of soil erosion in New Zealand come to mind as examples of what geographers have recently been doing.

Cartography is of course our major tool, one of our keenest instruments of research, and the best means of geographical expression. Maps of population, of production, of circulation point to the lamentable consequences of partition, whether in Palestine, in India or in Germany. Our forefathers explained the diversity of resources between region and region as the Creator's device for bringing men together in peaceful, friendly business intercourse. To-day that diversity is exploited as a political weapon.

A new light on regional differentiation in the past will be cast by the mapping of the Domesday survey of 1086, which is now in progress. Comparison will be possible with that modern Domesday, the *Land Utilisation Survey*, which provides us with basic material both in pure and applied geography, and has become part of the accepted equipment of the physical planner. Further light is being thrown on the stability of land-use where the soils of high quality are concerned by the laborious reconstruction of field maps by research workers interested in historical agriculture. These maps show how the land was farmed early in the 19th century, and in a few cases it has been possible to reconstruct the exact country scene as far back as the days of the Armada.

It is very desirable that these investigations of agricultural land-use should be matched by an equally comprehensive mapping of urban land and building use in all our towns. Considerable work on urban geography has already been carried out at Oxford, and elsewhere there have been several individual surveys of towns, their functions, social structure, regions of circulation and relations with the adjacent countryside. But there has been no co-ordinated over-all study. Researches of this character are, however, very necessary if faulty town and country planning is to be avoided, for we need to obtain a much firmer grasp of the anatomy and growth of towns as functioning organisms, reflecting the circumstances of place. It is apparent to geographers that those experts who plan to 'create' new towns, and to 'decant' people in their tens of thousands from one area into another have little appreciation of the interplay of geographical factors which results in one sort of human agglomeration growing up just at this place and another just at that. Looked at either in detail or as a whole the urban pattern of Britain, or indeed of any other country, is not a random one.

Many physical planners, however, do seek the co-operation of geographers, who in particular have been associated with them in examining the potentialities of the Development Areas. Experience has thus been gained in group work as distinct from team work, that is to say persons of different skills—architects, engineers, industrialists, sociologists, geographers—have got to work together upon particular problems of reconstruction. While the first results are naturally not completely satisfying, they are well worth careful study. Such publications as *English County* (Herefordshire), *English County Town* (Worcester) and the survey and plan for *Middlesbrough*, besides monographs on Liverpool, West Cumberland, Tyneside and South Wales are among examples that come to mind. Nor should we overlook the very important output of the Maps Office at the Ministry of Town and Country Planning directed and staffed by geographers, some of it on exhibition here.

In harmony with the general theme of this meeting of the British Association, I have been touching upon aspects of geography which have social applications. War is, however, also part of our social history, and the older among us have twice experienced the sudden rise of geographical prestige which occurs in war time. In broad terms, geographical intelligence of every kind then becomes vital, and while many of our number were seconded to various Ministries during the war—to the Ministries of Information, of Economic Warfare, of Supply, and so on—others have honourable records of

organising and supplying geographical intelligence to the various Commands, and in many cases of adapting, interpreting and applying such intelligence to the novel and intricate needs of commandos, bomber-pilots and others engaged in particular operations. Exactly how they worked cannot be disclosed for reasons of security, so these very few words must not be regarded as an index of the importance of what they accomplished. Nor can I speak in detail of the groups who compiled a library of geographical volumes to the specifications of the Admiralty, although it must be emphasised that these and the Terrain Handbooks that came from the intelligence service suffer very much from the geographical standpoint because of the gazetteer style imposed from above. Many of our younger geographers helped to fill the rapidly expanded ranks of the Meteorological Branch of the R.A.F., both as instructors and forecasters, while the first officer commissioned in the new Meteorological Branch of the Royal Navy was a university geographer. To cope with attack and defence in the third dimension demanded a new type of meteorology, a meteorology in depth, or rather in height, that had not hitherto been part of the sailor's equipment.

There can of course be no applied geography unless there has first of all been an adequate pure geography. Preoccupation with the genesis of slopes and facets, for example, reflects the fact that in a sense all geography springs from an exact knowledge of surface relief. The layman, however, must have been really puzzled to learn that a Gold Medal of the Royal Geographical Society had been awarded for researches in Geodesy, and not less so when he learned what the word meant. We ourselves are perhaps startled to hear it suggested that the exact size and shape of the earth may be elevated to the rank of 'top secrets': startled until we remember that success in mechanical warfare depends upon pinpointing the target—a target out of sight round the bulge of the earth. Yet since we possess maps of the world the problem might seem to be one of computation only until we recall that a mere fraction of the land surface has been covered by instrumental survey of the order of precision really necessary, and that the tying together of such exact surveys as are complete has often not been done directly on the ground (indeed the oceans intervene) but by calculation based on an assumed figure of the earth. If the map of Burma were much less than the ten miles, or ten minutes of the arc, out of the true that has been hinted, then while radar-directed planes or atom-bomb-loaded rockets might reach the latitude and longitude at which they were aimed, they would not reach their targets. The earth as a globe has proved progressively disappointing. Eratosthenes, over two millennia ago, assumed it a perfect, static sphere and hence deduced all its dimensions from a single measurement. Ptolemy in his turn fitted the map to the graticule by simple arithmetic on the same assumption, having a mere dozen or so of astronomical 'fixes.' When members of the French Academy first measured the degree by triangulation along the meridian in the 17th century, the scientific world believed that they had found at last a universal standard of length which could always be recovered if it were lost. Only Robert Hooke became immediately doubtful. Would not a spinning globe be spheroidal in shape? Were the poles constant? Was the earth subject to radial shrinkage? To-day we can only say of the earth that it is earth-shaped—a geoid: the surface of equal gravity potential has no geometrical regularity, and we still know too little of its irregularities to be quite certain of destroying Hollywood from Timbuctoo.

For a country to be ill-mapped might, it is clear, provide a species of camouflage. But for the fighting man, apart from exact position, there is no detail of the terrain so minute as to be completely unimportant, and the future lies in photogrammetry—in stereoscopic surveying and mapping from the air from which there is no defence. The remarkable results obtainable by ordinary air-photography in the fields of archæology and structural geology have long been familiar, but great technical difficulties had to be overcome in plotting accurate maps from stereoscopic air surveys which provide precise data for contouring. The creation of a University Chair in Photogrammetry and Surveying, associated with ample funds for equipment, reflects an important advance in cartographical technique, and holds out immediate possibilities of rapid and continuous mapping for civilian purposes. The scientific interpretation of air-photographs has also played a very important part in warfare, and has occupied many trained geographers. Not only do they afford means of picking out targets and examining enemy dispositions, but inferences can be drawn from them as to the nature of the ground, the degree of forward visibility, the lines of movement possible and degree of cover afforded for different categories of troops and vehicles. A skilled user can pick out the different types of forest, woodland and bush and hence forecast the conditions as regards varying difficulty of penetration and amount of cover. Varieties of crops can also be detected, vineyards, rice-fields, sugar and so on, and these

give a clue to the terrain, whether water-logged, well-drained, sloping, intersected by ditches and so forth. Vegetation, crops and soil types all vary as to the extent to which the disturbance or break-down caused by troop and vehicle movements leaves results easily detected by air reconnaissance, and this too can be foreseen by photographic study. Some of you will perhaps remember photographs of our English Fens which picked out the *roddons*, the vanished silt-filled watercourses through the peat, an example of how soil-texture differences, invisible on the ground, can be detected from the air.

Colour photography and photography with different wave-lengths is even more effective. It can make nonsense of camouflage, and reveal conditions at depth both on land and sea. In peace it could provide far more precise crop-forecasting than farmers' estimates, and be cheaper than collecting doubtful statistics.

A difficulty arises, as all who have used the French 1/50,000 maps are aware, when much detail of crops and vegetation is plotted on the topographical map, for it is apt to obscure the contouring and hill-shading—that is to say equally vital information about slopes. Our English survey maps achieve clarity by leaving out much that we should like to know, and the general question of map design, map content, map conventions and map draughtsmanship is worth more serious attention from geographers than it has yet received. To take but a trivial example, the ordinary draughtsman, trained only to use his pen, is little concerned if his neat placing of a name should result in ambiguity as to the exact village or topographical feature to which it should be attached. Yet such an ambiguity may have disastrous consequences in war, and is of course undesirable at any time. Nor, too, should ambiguous or unexplained conventional signs be tolerated, and in this connection an anecdote told to me by the well-known physicist who supplied me with this material about Geography in War is very instructive. The line drawn on the map (a derivative of the old 1/80,000) to mark a certain Normandy river in the line of advance was broken between two points. A draughtsman's error was assumed, and the course of the river reconstructed. Actually, however, it was limestone country and the water had simply disappeared underground. Further deductions were however made from the size and character of the drainage area as to the approximate width and depth of the river in its different reaches, and dispositions for crossing it made accordingly. But in point of fact the upper waters above the 'perte' pursued an independent course by underground channels to the sea, while the beheaded river when it reappeared was an inconsiderable stream that presented no obstacle whatsoever. One moral of this tale seems to be that geomorphology should be part of the education of at least some elements of Army personnel. A foreknowledge of the whole assemblage of surface features to be expected in a particular type of country, whether chalk, limestone, clay, formerly glaciated, rejuvenated or whatever it might be, would allow of valuable forecasts as to water supply, vegetation, location and grouping of habitations and many other matters. Conversely the presence of certain tell-tale features on the map would indicate to the trained observer the character of the terrain: the boundary between chalk and clay, for example, with all its implications for good going, is sharply marked. Modern geography, however, is not included in the education of the young officer, and an examination of his Map-reading Manual, excellent although it is in many respects, reveals an astonishingly meagre and out-moded vocabulary for the description of surface relief—a vocabulary that can be traced back to French military manuals of the last century. An object for which we have no name is likely to go unnoticed, or at best be very clumsily described, and an officer's reconnaissance notes would certainly gain were he master of the rich and precise topographical vocabulary which geography employs.

In general, however, the fighting forces had to master their geography as the war proceeded, and a most remarkable piece of *ad hoc* geographical research and geographical synthesis was carried out as part of the preparation for the beach landings of D-day. Of the part played by geographers in intelligence work relative to the Sicilian and Anzio beaches I have only vaguely heard and so cannot pay them their just tribute. In respect of Normandy the problems were sorted out, the right questions asked, the methods of answering them suggested and the totality of information brought together by the physicist I have already mentioned.

Land, sea and air were alike involved, and a simple fact, familiar enough to geographers, that there is no such thing as a coast 'line' except on small-scale maps was brought into sharp relief by a question of etiquette. Exactly when, in the case of amphibious craft, or of men and vehicles moving in the sea, was authority transferred from the Navy to the Army? Actually the major material problem was to provide 'going maps' for vehicles of very varied types, from jeeps to tanks, across a belt which embraced the adjacent sea-floor as well as the beach itself. Slopes, depths, and the character, texture

and weight-bearing properties of the littoral deposits, both exposed and concealed, had all to be determined and their distribution mapped : but all had to be done in England or from the air. High Authority however, typically mistrusting scientific deduction, did send out a single commando equipped with augers to bring back a sequence of cores obtained at intervals along a single traverse up the beach. So, too, does the airman, mistrusting his instruments, dive down through the clouds for a fatal ' look-see.'

It might of course be thought that the Admiralty Charts, with their French counterparts, together with the large-scale survey maps of France—copies of all of which were in our possession—would supply all the needful information. This was not so : there was mention of charts with an ancestry going back to 1780, and it is certainly the case that the foreshore and the inshore waters too shallow for ordinary shipping form a sort of no-man's land receiving little attention on map or chart. The situation is further aggravated by the fact that there is no terrain more subject to rapid and irregular alteration. Not only are sweeping changes brought about by the shore-line processes of erosion and deposition, but sea level is subject both to short-term and secular change. ' The sea level ' like ' the coast-line ' is a concept rather than a reality.

While one is tempted to think that, in spite of these obvious difficulties, the physicist was ill served by the regional geographers (a variety of the species not to be found in every university), yet it is a fact that he started his researches in the local guide-book, from which he learned that the peasants used to go out at low spring tides and bring in a mysterious fertiliser from the sea. This was not seaweed as one might at first suppose, but peat. Extensive peat-beds, the counterpart of our submerged forests, but possibly associated with a later positive change of sea level, lie off the shores of Calvados, and these and other likely sub-aerial features, including in-filled river-channels, associated with a drowned coast had to be taken into consideration. Accumulations of mud and silt are not of course necessarily the result of change of sea level, and the chance clue of a place-name on the map indicating a seaport where none now existed prompted some historical research. This resulted in the information that the name was indeed the sole relic, other than documentary, of a once flourishing mediæval harbour which had become choked up subsequently to the 14th century. It must not be supposed, of course, that our physicist turned directly from accustomed researches on the spatial relations of the atoms in the molecule to the perusal of old French manuscripts. He had his specialist advisers, including his geographical assistants, to whom all credit is due for their services. The documentary sources which they ransacked included the proceedings of local scientific societies—archæological, botanical and particularly ecological—and in particular one hundred years of the records of the Linnæan Society of Caen, which revealed, for example, the points at which hardy folk could cross the marshes or scale the cliffs.

The tides, which of course varied the depth of water all round the clock, presented a difficulty, since, as it appears, neither the Admiralty nor the Liverpool tidal institute could supply the most recent French tide-prediction tables, nor was it realised that these could have been obtained through the French Resistance movement. Supposing the rise and fall of the water to be known and the distance between high and low tide-line observed, then the beach gradient, an essential piece of information, can be calculated. To check and revise tide-tables indirect methods were therefore resorted to, some applicable to Normandy, others to the Mediterranean and the Pacific. It was ascertained that wave velocity (which could be observed) was a function of depth, while in the absence of waves colour served as an indicator. Still, turbid water required yet another method, and the depth was ascertained by measuring the height of the plume of water raised by dropping a bomb of known calibre, the two phenomena being related. All these methods gave results within the order of accuracy required. Another problem which was solved was the determination of the height of the surf as it fell on the beach ; for too much surf, such as was encountered in Africa, would obviously interfere with landing. It was found that the surf dimensions are a function of the height and wavelength of the swell, and since the run of the swell can be observed far out to sea, while it is set up by the previous and not the current meteorological conditions it is susceptible of exact prediction. Surf prediction proved vital in the Pacific landings, which fortunately were not made in the early period of the War.

In regard to the beach material and underwater deposits, it was necessary, of course, to know not merely the character of the superficial layer, but its thickness and the nature of the substratum on which it rested. A jeep, for instance, could run across mud or peat if there was a comparatively thin layer of firm sand or shingle on top of it. A heavy vehicle, on the other hand, would break through the crust and become hopelessly bogged or even disappear. When, however, mud or clay

formed a thin veneer over sand, the situation was reversed. The light vehicle became immobilised while the movement of, say, a heavy tank, which could get a grip on the substratum, was hardly interfered with. To ascertain the limiting conditions imposed by various types and thicknesses of stratification, experiments were made in an English coastal area which matched as nearly as possible the problem area in Normandy. Further information was obtained by producing and observing bomb craters on the spot. Sand craters, as every beach-digging infant knows, quickly fill and disappear, whereas mud-craters hold water and have very definite stability. Geographical "matching," incidentally, allowed the rehearsal and subsequent magnificent success of a spectacular assault on a German battery on the top of a 200 ft. vertical cliff.

Many new ideas regarding shore-line processes emerged, in particular as to the relation between wavelength and deposition, and the part played by the fetch of the waves in producing a long 'simple' beach as opposed to a compound beach made up of separate units. The name of Brigadier Bagnold, whose researches between the two wars into the motion of desert sands proved so fruitful, was associated with these new investigations, and it was discovered, for example, that the observed juxtaposition of shingle and mud arises from the fact that down to a limiting size pebbles are broken down by hammering and splitting, but below that size by grinding and trituration.

For a clear picture of all that was accomplished for pure science in the course of these investigations we must await published reports. My immediate purpose in presenting this sketch of Beach Reconnaissance is to illustrate the importance of geographical knowledge and also to show how it is only by knitting together a great number of separate threads that we can describe and interpret the totality of terrestrial features that gives its distinctive character to each part of the Earth's surface.

In one shape or another, the idea of the map as a means of presenting to the eye this totality of features has been continuously in the background of this discourse. And I wish to press the point that if the recognition of the regional differentiation occurring within the framework of the earth as a functioning organic whole is to become, as it should, part of the mental background of every thinking person, then much more attention should be paid to maps and globes. A *National Atlas* would display the diversity in unity which characterizes every aspect of the physical and human geography of our own country. We shall discuss such an *Atlas* during the week. A Rolling Globe and its accompanying transparent hemisphere carrying a universal graticule of true bearings and distances is the latest device for curing an obstinate adhesion to the distorted World view inculcated by Mercator's map. 'Science is a study of the inter-relatedness of things.' In Geography we study each country, each region, as an integral part of One World, but it is still true that one aspect of our work must be to 'remove the Rubbish, lay in the Materials, and put things in order for the Building.'

SECTION F.—ECONOMICS AND STATISTICS

THE ECONOMIC OUTLOOK

ADDRESS BY

PROF. D. H. ROBERTSON

PRESIDENT OF THE SECTION

1. WE have been bidden by the Council of the Association to make our sectional programme conform to the general theme of the conversion of Swords into Ploughshares. I am not sure that we have completely succeeded; though perhaps even the more esoteric items in our programme can put up as good a claim to conformity as some of the fascinating topics to be discussed by other sections, for instance the diseases of raspberries. Anyway, it was with a laudable intention of conformity that I chose, many months ago, the title which has been published for this address. But that choice proved to have two disadvantages. First, with the rapidly changing pattern of economic events, it proved psychologically impossible to set about writing my paper in time for its inclusion in the usual volume. And, secondly, when I *did* come to write it, I found in myself an invincible repugnance towards doing what I knew I ought to do,—serving up in more or less palatable form the latest available information about our situation in respect of man-power, of fuel, of the balance of payments and so forth. I found myself instead impelled to discuss—though not, I hope, altogether without regard to that information—certain broader questions of a more general and philosophical kind. I am only too conscious that I have thus doubly let the Section down. I have failed to keep the fact of its existence prominently before our confrères of the scientific world; and now, in what I have to say, I shall do nothing to redeem the claim of economics to be among the sciences, but shall rather give fresh occasion for the charge that the economist is an outmoded adventurer, moving uneasily between the two worlds that really matter, the technical world on the one hand and the spiritual world on the other, with a foot in both and an assured position in neither. Perhaps, since no real scientist will read this address, my two crimes go some way to cancel each other out; but all the same I ask your forgiveness for them both.[1]

2. The problem on which I propose to offer some reflections, and to ask you in your turn to throw light, is that of the general economic framework within which this conversion of Swords into Ploughshares is to be completed. There is a widespread and growing conviction that its completion requires something called a National Plan,—that for the purpose of effecting it our country must become or remain something which, by contrast with our pre-war arrangements, can fairly be described as a Planned Economy. Nine months ago, for the benefit of some Dutch students to whom I had an obligation, I tried to set down some thoughts on this concept of the Planned Economy; and since that paper has not been published in this country I shall think no shame to lift from it a few sentences which I still find to my purpose. But since it was written many things have happened, both in the world of fact and in the world of words. In the world of fact, it has become plain, in the terse words of one of our great industrial leaders,[2] that 'the partial success which attended the country's spurt in production in 1946 was misleading and was accomplished at the expense of eating up available stocks of raw materials and component parts.' It has become plain, too, that our external position is far more difficult than most people had realised, and that these difficulties themselves are part of a wider problem of œcumenical unbalance for which there is no precedent, and which calls, it has now been recognised,

[1] It has, after all, proved possible to include Prof. Robertson's address in this volume. He desires to call particular attention to the fact that it was dispatched for printing on August 3, when the Government's plans for dealing with 'the economic crisis' were still undisclosed.—ED.

[2] Sir Alexander Roger, K.C.I.E., statement as Chairman of British Insulated Callender's Cables, June 1947.

for wholly exceptional action. In the world of words, the Government has endeavoured to explain in an official paper the concept of economic planning to which it believes itself to be working ; and the Opposition has endeavoured to explain, in a document bearing the now fashionable title of ' Charter ', just how far its own conception differs from that of the Government. In addition, three distinguished scholars, each of whom played a notable part in war-time economic administration, have in public lectures on this theme nobly tried to share with us the fruits of their experience and their reflection. There is plenty of material to discuss : the difficulty is to say anything about it, especially in a short space of time, which does not melt away in the ears into wool and water.

3. Let me waste a little of that precious time in disclosing to you, in order that you may discount it, the bias of mind with which I approach this whole matter. It is, as you know, that of a disciple of the ' Cambridge School ' of economics, the puny wearer of the giant mantle of Marshall and Pigou. Now this school, though in a sense the heir, on the economic side, of the great tradition of English philosophical Liberalism, was never very rigidly ' Liberal ' in the sense in which that term has sometimes been interpreted on the Continent. It was acutely aware of the evils which can arise out of the unfettered exercise of ' economic freedom '. The case for redistributive taxation, for measures of social security, for the better organisation of the labour market, for central leadership and discipline in the domain of money and banking, for the public operation of some branches of economic activity,—all this was part of the stock-in-trade of the Cambridge student of economics in the 1920's and indeed in the early 1910's ; and so were more recondite arguments for attempting to improve the distribution of the nation's productive resources between different employments. Even the idea of Government action to mitigate the force of industrial depression was not so unfamiliar to us in those distant days before the first world war as is now sometimes supposed. If one Cambridge-educated economist could oppose a ' policy of public works ' on the ground that it involved ' withdrawing from the investment market savings which would otherwise be applied to the creation of capital ', it was another who could reply, as long ago as 1914, that ' the whole point is that in time of depression savings are *not* otherwise so applied ' !

Nevertheless, it is, I think, fair and illuminating to say that the ideas on which we were brought up would be more truthfully summed up in the phrase ' judicious State intervention ' than in the now fashionable watchword of ' the planned economy '. We were taught to think rather in terms of tinkering at the systems of private property and economic freedom—freedom of occupation for a man's self and his possessions—than of replacing them or even of binding them in chains. Was it simply because our teachers, being pragmatic Englishmen, expressed themselves naturally in terms of ' the next thing to be done ',—what wants mending in the house or digging up in the kitchen garden this morning ? I think there was a little more to it than that. Or was it because, whatever they seemed to themselves and to us, they were in fact merely the lackeys and parasites of an oppressive ruling class ? Frankly, I don't think there was as much to it as *that* ! I think the truth is rather that their work was permeated with two beliefs, which may or may not have been mistaken, but which were at any rate based on honest observation and deep reflection.

One of these beliefs is concerned with human motive, and is crystallised in a sentence of Marshall, to which I often find myself recurring (the italics are mine) :—' progress mainly depends on the extent to which the *strongest*, and not merely the *highest*, forces of human nature can be utilised for the increase of social good '. If that seems cynical, it is surely cynicism of a very gentle and mellow kind, calculated to promote right judgment and to forestall disillusionment. The other belief is concerned with the limitations of human knowledge and the fallibility of human foresight. Our teachers did not quite believe with Adam Smith (who in point of fact did not quite believe it himself !) that the study of a man's own advantage ' naturally or rather necessarily ' leads him to prefer that employment of his resources which is most advantageous to society. But they did, I think, believe that in this highly uncertain world there is *prima facie* great advantage in having responsibility for the use of resources *dispersed* as widely as possible, on the ground that out of the welter of individual judgments—judgments exercised both in production and consumption—a more satisfactory result is likely to emerge than could ever be achieved in practice by a single all-directing will.

4. I have indulged in this little retrospect because it is important, I think, neither to exaggerate nor to conceal the difference between the philosophy of economic liberalism as it has developed in this country and the philosophy of the planned economy. It is foolish to speak as though the difference between them were the difference between anarchy and order, between the jungle and the sown. But neither does it seem at all

clear that there is no real difference of kind, but only a difference of degree and pace, between the conception of Liberal Interventionism on the one hand and the conception of the Planned Economy on the other,—the conception that now and henceforward it is incumbent upon the State to frame and administer a concrete master-plan for the full and effective use of all our economic resources—a plan within the four walls of which the plans of individuals, producers and consumers alike, must accommodate themselves as best they can. Those of us, therefore, who are handicapped—if you so regard it—by the kind of congenital or educational bias which I have tried to describe have a real personal problem to solve. How far can we honestly manage to attune our thoughts and our teaching to the prevailing wind? And in so far as we fail to do so, is there nothing for us but to adopt the stance—an honourable stance, but emotionally fatiguing and apt to be operationally sterile—of owls in the desert and pelicans in the wilderness, praising past times and prophesying doom?

5. In his Marshall Lectures delivered at Cambridge in May,[1] Professor Lionel Robbins has made a notable attempt to redeem us from owl-hood and set us confidently on our own feet. In these lectures, as you will see when they are in your hands, he set himself to do three things. First, he drove home the inherent difference between the single all-subsuming objective of a nation at war and the diffused many-headed objective of a nation at peace. 'Of course,' said he, 'if it gives you any satisfaction you can still provide a formal description of the ultimate [peace-time] goal which has a unitary appearance. Nobody is likely to quarrel with the statement that the object of policy should be to maximise welfare over time. But this is to state the problem not to solve it.' And he proceeded to develop with great lucidity and force the case for entrusting the solution, with well-understood exceptions, to the operation of the market, that 'process of election', as he described it, 'which not only allows proportionate registration of minority opinion, but also continuous review of producers' decisions by those most immediately concerned with their ultimate results.'

Secondly, he laid much stress on the positive aspects of a liberal policy. He gave his blessing to the view that the powers and information at the disposal of Governments are now such as to justify them in taking much more active steps to influence the total level of industrial activity than would have seemed feasible thirty years ago to those of us who even then discerned in the damaging alternation of boom and slump the weakest link in the chain of economic freedom; though he declined, wisely in my opinion, to describe such a policy by any such over-ambitious title as 'planning for full employment'. And in other fields, too, he reminded us, there is much to be done. The continuous amendment of the legal framework within which the play of economic motive is allowed to operate, the continuous adjustment of the ceilings and floors limiting the effects of its impact on individual lives,—these would in any event be positive and arduous tasks, well begun by those who have gone before us, but of their nature never complete.

Thirdly, as befitted one only lately released from the responsible rôle of *médecin malgé lui*, he kept our feet on the ground by disclaiming any intention of advocating a premature dismantling of war-time controls while pressures only too similar in many ways to those of war are still upon us. Not a precipitate return to *laissez-faire*, but a reconsideration of inflated programmes and a progressively increasing use of market mechanisms,—these were his prescriptions for the period of transition through which inevitably we have to pass.

Now here evidently is a pattern of thought and activity highly attractive to those of us with the liberal virus in our blood but unwilling to be banished to the desert or the wilderness. But it is evident, too, I think, that its strength as a sheet-anchor for our thoughts depends partly on the validity of that convenient antithesis between the period of transition and the post-war normal which has figured in so many discussions from the Coalition Government's White Paper on Employment Policy onwards, and has even found sanction in legal instruments such as the Bretton Woods agreements. And one of the questions to which my paper this morning is intended to lead up is precisely whether this antithesis is one which it is still sensible to draw, or whether the lesions caused or precipitated in our economy by the war are now revealed as being of so deep and lasting a character that this distinction between the transitional and the permanent must be thrown, with relief or regret according to our temperaments, upon the scrap heap.

6. Before facing that question, however, let us see what comfort, if any, we sufferers from the bug of liberalism can derive from the utterances of certain parties who, while much more favourably disposed to peace-time planning than Lionel Robbins, are yet concerned to assure us that the Kremlin is not their spiritual home.

I turn first to a line of thought thrown out by one who would certainly not describe himself as a 100 per cent. planner. In his

[1] *The Economic Problem in Peace and War*. To be published shortly by Macmillan and Co.

brilliant Rede lecture,[1] also given at Cambridge in May, Professor Sir Hubert Henderson identified the essence of planning as consisting in the formulation of precise quantitative programmes extending over a considerable range of time ahead, and set himself to investigate the limits within which, in time of peace, such programmes can be expected to serve as useful instruments of action. He found his answer by drawing a sharp line, or rather, as we shall see, a line blurred only at one critical point, between what modern jargon calls the public and the private sector of economic life. Where the Government has taken over the task of *production*, there it can and must plan like any other producer. Further, where it is the chief *consumer*, it can plan its requirements in a manner which dominates the market situation : and in this connexion, says Sir Hubert, we must distinguish between the component items of really long-term investment programmes—houses, generating stations and so forth—in which this condition of Government preponderance in the market is now perhaps fulfilled, and the shorter-lived and more various category of industrial machinery, in which it is not. Imports also —and this is the partial blur in the line to which I alluded just now—the Government must plan, albeit that even in these days of bulk purchase it is not the sole buyer. But when we come to exports, and indeed to the general field of ordinary production and trade, the Government *cannot* enforce its programmes, cannot therefore effectively plan, and cannot therefore usefully pretend to do so.

I came away from Henderson's lecture not only pleasantly tickled by his deft puncturing of the balloons of the more ambitious practitioners of the sport of economic model-making, but, for the moment, definitely consoled. Here, perhaps, was a solution. Governments might indeed, as he had pointed out, do some harm by publishing unenforceable targets and trying to plan the unplannable ; but in time they would doubtless learn, and if we possessed our souls in patience and did not take wing prematurely for the desert and the wilderness, we should find that things had settled down to a new equilibrium, with a planned public sector of economic life and an unplanned private sector. But when I read the lecture again I began to doubt. For one thing, did not those import programmes, with all their inevitable repercussions, constitute an abiding threat to the clarity of his dividing-line ? For another, had he not underestimated the potency of what I have called, on another occasion, ' the characteristic English processes of jollying along,—of encouragements which are not quite promises, frowns which are not quite prohibitions, understandings which are not quite agreements ' ? I felt that he had rested his case too little for my taste on the positive merits of a free system, and too much on the weakness of the weapons at his disposal for supplanting it. If he should once discover that those weapons were stronger than he thought, there might, I almost feared, be no holding him !

7. I turn to some presentations of the theory of planning in which those jollying processes, which Henderson's sharp dichotomy tends, I have suggested, to overlook, are glorified and idealised until they become the solvent of all our doubts and difficulties. That there are doubts and difficulties to be resolved is, I think, not denied. Let us look first at the Government's own statement,– the now famous introductory section of the *Economic Survey for 1947*. This, as has been pointed out on many hands,[2] is a very curious document. It draws a sharp contrast between democratic planning, which takes account of the fact that ' in normal times the people of a democratic country will not give up their freedom of choice to their Government ', and totalitarian planning, which ' subordinates all individual desires and preferences to the demands of the State.' Yet only a few lines later we learn that under democratic planning it is the Government which is to ' formulate the national needs ' and to ' say what is the best use for the resources in the national interest '. The people's freedom of choice is not to be interfered with ; yet we must prevent a situation arising in which there are, for instance, ' too many toys and not enough children's boots '. In the democratic no less than in the totalitarian State it is the Government which is to decide which are the ' national priorities ' (or rather—a specially intriguing phrase—which are ' the more important national priorities '), just as the shopping housewife makes decisions for the family. It is not until we get to the execution of the plan that the difference between the totalitarian and democratic State clearly emerges. The latter, it is true, now has at its disposal ' a large number of direct controls ', which it can use to influence the course of production. Among these is rather naïvely mentioned price control, which ' influences the course of production by limiting profit margins ' : it is not explained that this influence works pro tanto *against* the expansion of the output of those essentials whose prices are subjected to control. This, however, is by the way ; the main point is the

[1] *The Uses and Abuses of Economic Planning* (Cambridge University Press).

[2] See especially the article by John Jewkes and E. Devons in *Lloyds Bank Review*, April 1947.

White Paper's conclusion that, in spite of the existence of the controls, 'the task of directing by democratic methods an economic system as large and complex as ours is far beyond the power of any Governmental machine working by itself, no matter how efficient it may be'. It can only be secured by the co-operation of 'both sides of industry and the people' (another intriguing phrase which bears thinking about),—the function of such co-operation being presumably not only to carry the plan into effect, but to iron out, as it were, *ex post* any disharmony which may have appeared in the plan between what people thought they wanted and what the Government knew they really did want.

It is of course easy for academic persons with infinite leisure—or so it is commonly supposed—to pick verbal holes in documents drafted by overworked civil servants and initialled by distracted ministers. But it is not, I think, surprising that the amiable woolliness of this particular document should have occasioned some bewilderment. Nor was that bewilderment allayed by the explanation given soon afterwards by a very highly placed person indeed of the precise manner in which, in respect of its most crucial aspect, this co-operation of the be-planned people with the planning Government was expected to implement itself. For of course the crux of the whole matter is that generally speaking, except when occasionally they roll upon the floor, the housewife's shillings and pence can be relied upon to go where they are told, and generally speaking the Minister of Labour's men and women can not. 'Ask yourself' whispered the very highly placed person into the ear of each one of us one evening, 'ask yourself whether you are doing the kind of work which the nation needs, in view of the shortage of labour. Your job may bring you in more money, but be quite useless to the community.' It is not recorded that on the following morning a gigantic game of conscience-stricken general-post took place. But if it *had* done, might not the results have borne a closer resemblance to chaos than to a planned economy? I seem to hear that gentle warning of Marshall's from beyond the grave, 'Progress mainly depends on the extent to which the *strongest* and not merely the *highest* forces of human nature can be utilised for the increase of social good'.

8. Oppositions, or so it is to be supposed, have more time for reflection than Governments; so let us turn to that in many ways very notable document entitled 'An Industrial Charter' to see whether it throws any sharper light on that functional boundary line of which we are all—yes, even the owls and pelicans among us—in search. There can be no doubt, I think, that some of the individual planks in this programme are in closer accord with the philosophy of what I have called Liberal Interventionism than with that of what is usually thought of as a planned economy. For they recognise that that *dispersal* of decision-making power which I have pointed to as one of the guiding principles of the liberal philosophy is not the same thing as mere *delegation*. The distinction is, I think, important. If an army commander gives general orders to a divisional commander, he at the same time delegates to the latter the duty of giving more detailed orders to *his* subordinates; and it is universally agreed that it will not usually make for efficiency if the army commander then butts in to see exactly what those orders are and how they are being carried out. But there is nothing in this to alter the fact that if the army commander's plan is wrong, the whole army comes to grief. The dispersal of economic judgment commended by the liberal philosophy meant something much more than this: it was not merely a device for promoting administrative efficiency, but a recipe for securing that all the eggs should not be in the same basket,—that in this highly uncertain world the fortunes of a whole trade, or a whole area, should not depend on the foresight and the judgment of a single centre of decision. Now, as I have said, in some of their specific proposals, such as those dealing with the commodity markets and with road transport, the authors of the 'Industrial Charter' appear to be nailing their flag to this mast. But in their more general exposition of the process of plan-making, they flutter continually towards that alluring metaphorical candle, the distinction between the 'strategic' decisions to be taken by Government and the 'tactical' decisions to be delegated to industry, towards which, by the way, that substantial moth the editor of the *Economist* is also not infrequently found to be hovering: so that in the end we are not too sure, any more than in the case of the Government White Paper, what is really being said. One thing, however, seems to be fairly clear. In the co-operative process of plan-making and plan-execution, a very large part is to be played by bodies representing organised industries. So long, for instance, as the control of raw materials lasts, it is by 'the industries themselves' that allocation between individual users is to be carried out, though the Government would satisfy itself that the schemes of allocation are fair. One thinks of that intriguing phrase in the White Paper, 'both sides of industry and the people': is it cynical to wonder whether under this semi-corporative set-up 'the people' may not

sometimes come out a bad third? I confess that the composition of the new Planning Board, with its carefully balanced representation of the gigantic federations of capital and labour, has not removed my misgivings.

9. This conception of active participation by organised industry both in the framing and the execution of plans plays an equally prominent part in the most weighty and elaborate of the expositions of the philosophy of planning which I have set myself to consider,—the lectures given in the University of London last March by Provost Sir Oliver Franks.[1] It need hardly be said that this discussion by a distinguished philosopher, who rose within a short time to one of the highest posts in the administration of the war economy and who has lately been called back to the service of the country in connexion with the Marshall offer, deserves close attention, and that I run grave risks of doing it injustice by compressing my comments on it into the space of a few minutes. For reasons which centre on our international trading situation, Sir Oliver has become convinced that central planning in this country is absolutely essential, not merely for a short period of transition, but for as long ahead as it is useful to look. He conceives of the essential element of such planning as consisting in 'decisions of policy quantitatively expressed in the form of programmes and such measures as in particular circumstances may be necessary to ensure the performance of these programmes.' The actual programming is apparently to be confined to imports and exports; but these programmes are to be regarded as expressing 'an outline scheme of management for the total economy offering certain results in the standard of living for the people'. There is to be no woolliness or lack of precision as to what this scheme is or who is responsible for it: it is the Government which is to be 'committed to selecting and defining the ends of the national economy' in such wise as to render inapposite the old objection that 'the purposes of the nation in peace are multiple, vague and fluctuating'. Thus the Government is to find that 'it has gone into business management and become general manager of the national economy'.

Yet the decisions taken by the Government are only to be general in scope and as few in number as possible. Nor are they to be communicated to industry and commerce in the form of orders, for it is of the highest importance that initiative should be diffused throughout the system. 'Government will depend for the carrying out of its decisions on undertakings voluntarily given by industry and commerce.' Yet—and here comes the Hegelian synthesis—'the method of agreement does not leave business free to agree or disagree as it likes with the programmes laid upon it by Government'; for 'the condition of the method of agreement is [the] prior agreement to agree', based upon recognition of a community of purpose.

There are, I cannot help feeling, some disconcerting gaps in Sir Oliver's exposition. Nothing at all is said about that Achilles' heel of central planning, the direction of labour; it may be that we are to understand that Organised Labour, too, is to give a general undertaking to acquiesce in any programme that may be laid down and arrange a conformable distribution of the labour force. Again, industry is to be allowed to make reasonable profits, and profits depend on prices: but no clear indication is given as to what use the Government is to make of the price system in framing and implementing the programme of national needs. But even apart from these considerable omissions, I find that all my respect for Sir Oliver's intellect and experience does not enable me to feel that he has successfully reconciled certain fundamental contrasts. The contrast between those detailed statistical programmes, which are to be not merely 'statements of need' but 'acts of will' on the part of the Government, and the few and general decisions which it is to take on the basis of them. The contrast between the conception of free association and the conception of a chain of command—as to which here is one final quotation. 'Responsibility for different functions must be placed on those who perform them without equivocation and without strings.' I can see what that statement means as applied to an official in a hierarchy; but the business men are *not* to be officials, and the market mechanism which disciplines them under free enterprise is to be superseded, or so it would appear, by the national programme of needs.

10. Now once more, verbal criticism is easy; and to all this, if he could be here and were not better employed, Sir Oliver would, I fancy, make one reply. Do I, he would ask, reject his fundamental premiss—that for this country Governmental selection of *imports* is essential for as far ahead as it is any use trying to think? Or do I agree that we must now frankly abandon in this vital field that comforting distinction between the transitional and the post-war normal? And in that case, for an economy like ours into every cranny of which the tentacles of international trade penetrate, does not everything else follow,—the permanent central economic plan and the expedients, unsatisfactory as we may think them, for creating an aura of partnership and consent around its execution?

[1] *Central Planning and Control in War and Peace* (London School of Economics and Longmans, Green and Co.).

The second Great War, so I conceive the argument to run, has done something much more to us on the external side than create a set of temporary disabilities,—damaged and deteriorated plant, world food shortage, and so forth—which are plain for all to see but of which it is not unreasonable to look forward to a fairly early end. On the contrary, by the virtual obliteration of our net creditor position, by the stimulus which it has given to the manufacturing ambitions, in the sphere not only of consumable but of instrumental goods, of numerous overseas countries, it has precipitated something which in the fullness of time was destined to happen in any case,—the final showing-up of that precarious manner of life on which we heedlessly embarked a century and a quarter ago. The vital character of the majority of our surviving imports on the one hand, the limits to the possible extension of world trade in manufactures on the other, forbid us to suppose that our external equilibrium can ever be restored or maintained through trusting to the mechanism of the market, even as tempered by the cushions and flexibilities of the new international monetary mechanisms agreed at Bretton Woods. In these circumstances the restoration of consumer's sovereignty becomes an idle dream. The Government must perforce be trusted, in peace no less than in war or quasi-war, to make, in respect of imports, rough-and-ready judgments about the first things which shall come first,—judgments which, however vulnerable intellectually and however galling to minorities in their execution, do at least offer a prospect of preserving the fabric of social peace. It must be trusted no less, by whatever means it can command, to ensure that the selected imports are paid for by exports, since the play of self-interest can no longer provide any sufficient guarantee against the nation staggering along in a condition of mendicancy, ending when the external support is withdrawn in starvation and collapse.

I have put the case briefly, though I venture to think more persuasively than it is sometimes put by its exponents. I think it is a serious case deserving honest examination, and I hope to hear it discussed. Whether it be true or false, there is not much disagreement that the kinds of expedient to which it points,—import-restrictions, export-pressures—are, to revert to that old distinction between the transitional and the post-war normal, inescapable for the immediate future. Nor can the drift of world sentiment towards the obliteration of that consoling distinction be ignored. Of the numerous let-outs and saving clauses with which, when it last met the public gaze, the draft charter of the International Trade Organisation was found to be bristling, most, though not all, appeared to be without limit of time.

But there is surely another side to the story. I have been much encouraged to observe, in the commentaries of thoughtful persons during the last few months, a growing emphasis on the connexion between external problems and internal policy. There has been a growing tendency to re-discover that what are politely called ' balance of payment difficulties ' do not necessarily drop like a murrain from heaven, but that any nation which gives its mind to it can create them for itself in half an hour with the aid of the printing press and a strong trade union movement. That tendency to connect up has, it is true, not yet seriously infected our Chancellor of the Exchequer, who only a week or two ago took occasion to boast that ' the contrast is most remarkable between the great difficulty of the overseas position . . . and the relative ease of the purely domestic financial position, in which things are very much better and easier than we would have had any reason to expect two years ago ' : but perhaps he will hear of it in time. Until this side of the matter—the connexion between home financial policy and balance of payment troubles—has been explored and faced, it is surely far too early to give up hope of working our passage back to a state of affairs in which we can keep our heads above the international water without the aid of that mystical Frankish strait-waistcoat of a perpetual plan.

11. But that there is a passage to be worked, I have no doubt. Years of low-brow talk about production for use and not for profit, fewer but intenser years of high-brow talk about the humbug of finance and about investment breeding its own saving, have left us with a formidable web to unwind. Do you remember those words in the Planner's Song in *Through the Looking-glass*?

> ' But I was thinking of a plan
> To dye one's whiskers green,
> And always use so large a fan
> That they could not be seen.'

They throw some light, I think, on our predicament. A war economy demands, as we have found, not merely the underpinning of *general* standards of life, but the distribution of *particular* things according to need. And the result is that two different questions tend to get inextricably tangled up. The first is the question of how far we want to modify the distribution of income which the free play of economic forces would bring about. The second is the question of how far the satisfaction of wants should be organised *communally* instead of being left

to the operation of the market. Now the war has produced changes in both these fields which I think a wise man would judge to be not temporary but, in part at least, irreversible. The distribution of income has been altered in favour of the manual-working classes : and *some* of the extensions of communal action, such as the provision of cheap milk and vitamins to children, have certainly come to stay. But the way in which these two types of change have been interfused has left us in a bit of a tangle. The costs of these extensions of communalism have, so far as possible, been kept out of sight of the individual,—hidden behind ' so large a fan that they could not be seen ',—with the result, for instance, that for food subsidies alone the national budget is now bearing a charge of some £350 millions a year. And the consequence has been, as that saturnine jester Mr. Schwarz delights to remind us, the development of a certain schizophrenia on the part of the ordinary man : as a voter he plumps enthusiastically for house room and milk and medical attention ; as a spender of income he continues to plump for beer and cinemas and dog-racing tracks and perpetual motion by bus and tube and train. And all this happened at a time when it was necessary also to call upon him to make provision for the future, by the re-conditioning of plant and the righting of the balance of payments, on a scale which would anyhow have severely tested his willingness to part with the control of his own income for public ends. By what particular compound of resented restriction, unpalatable taxation and disillusioning curtailment of programmes we shall scramble out of the immediate mess I cannot forecast. But I am unregenerate in thinking that if we want to prevent its recurrence we shall have to beat a certain measure of retreat in this matter of communal or subsidised consumption. I think our planners must ask themselves very seriously whether in the long run first things can really be made to come first unless the *individual* develops the desire and the will to put and keep them first,—develops the readiness to pay, even for such essentials as food and house room, something much more closely approaching their full economic cost, and to limit his communal dreams to a range for which, when it comes to the point, he is really willing to fork out without more than the formal grumble to which every taxpayer has a traditional right.

Here are four sentences from a letter to *The Times*,[1] which met my eye just as I was struggling to compose this address, and which express with the refreshing directness of the practical man a good deal of what I have just been trying to say. ' If a man's wages go up and his expenditure on essentials is kept down by subsidies, where can his surplus purchasing power go except on inessentials ? The price mechanism is stultified. . . . We cannot restore the price system at a blow, but we can work toward it and not away from it. It is the only way of directing labour in a free society and incomparably the most effective in any society.'

Not at any rate until we have *tried* to work along that path do I feel disposed to admit that the seamless robe of Frankish corporativism is the only, or indeed likely to be the most efficient, wear in which to face whatever permanent readjustment of the national life is forced upon us by the ending, if it *has* ended, of that chapter which began when we set out with such splendid improvidence to become the workshop of the world.

12. I must bring these desultory reflections to a close. It may help to crystallise discussion if I remind you that in their course I have found occasion to examine certain closely-related distinctions which figure rather prominently in public debates on this theme of the planned economy, and invite you to shed further light on their meaning and validity.

The first is the distinction between arrangements appropriate to the *transitional* period and arrangements appropriate to the *normal post-war world.* Should we, in our thoughts and in our legal and diplomatic instruments, hold fast to this distinction as our best guarantee against the appetite for control growing by what it feeds upon, even though the transitional period bids fair to last much longer than we once may have hoped ? Or must we, as some would have us, decide that this antithesis has now become a humbug and a nuisance,—a polite periphrasis for split-mind, a cloak for what human beings always find so attractive, saying one thing and doing the opposite ?

The second distinction is that so much beloved of editors and broadcasters—the distinction between the *strategic* functions to be performed by Government in the economic field and the *tactical* functions to be performed by somebody else,—by Industry with a big I and Labour with a big L, or perhaps just by you and me. Can we give precise content and meaning to this metaphor, or does it rest on a false analogy between something which *is* an organised body under a definite chain of command and something—the nation in its economic aspect—which is *not* ?

The third is the distinction between the *Government sector* of economic life and the *private sector.* Is Henderson right in inking in that boundary line as marking the frontier

[1] By Col. Nigel Birch, M.P., July 19, 1947.

between the field in which precise quantitative programming is sensible, because it can be enforced by acts of will, and the field in which it is bound to degenerate into pipe-dreams? Or are those right who hope or fear, as the case may be, that in this country at least the mysterious processes of 'jollying along' can be so perfected as to render this boundary line of little account?

And the fourth distinction, the most important of all, is that distinction between *democratic* and *totalitarian* planning which is so flattering to our self-esteem, but which leaves the hard-boiled Liberal shaking his head and the hard-baked Communist chuckling up his sleeve. Do these two kinds of planning really differ in the quality of their ends, or only in the effectiveness of the means at their disposal for achieving those ends? And if that *is* the only difference, is there not a danger that the 'controlled economy' will always be living on the edge of a precipice—walking on a tight-rope with its head in a cloud of make-believe?

SECTION G.—ENGINEERING

PROGRESS IN MODERN ENGINEERING

ADDRESS BY

SIR WILLIAM HALCROW

PRESIDENT OF THE SECTION

MAY I start my address by thanking the members of the British Association for electing me President of Section G. I have taken as my subject ' Progress in Modern Engineering ' and have endeavoured to cover to some extent the three branches, namely—civil, mechanical, and electrical engineering, which will form subjects of papers to be read this week.

As my own professional life has been spent in the first of the three branches, it will form the principal topic of my talk.

The analysis of engineering evolution involves rather more than the mere consideration of the practical aspects of the subject. If we are to understand fully and interpret the past, we must take into account the mental conditioning of those times as well. Only in this way can we understand why progress took place in certain ways and at certain rates, and only thus can we gain any appreciation of trends in the near future.

It is difficult to realise to-day just how recent scientific education is. Even up to the end of the last century, higher education was mainly classical in outlook. The man with the scientific and inquiring mind was, to a great extent, his own teacher and was always subject to the prejudice and sometimes the abuse of the unenlightened. The mechanisation of society was still at a limited stage and, worse, it had been so for many generations. Conditioning by tradition was therefore very strong, and it is not surprising that progress in the engineering field at that time would be the result of the efforts of a few enlightened men and, further, that while their initial ideas would be a considerable step forward, development of the idea itself would not necessarily be either rapid or ingenious.

One is accustomed to think of the Industrial Revolution as a period of tremendous development, but it was really a period of tremendous invention and immediate application. In general the pace of development as such was slow right up to about the beginning of the present century, and it did not become really fast until after the first World War, when out society had become mechanically minded.

British development has naturally been influenced by that in other industrial countries, especially over the past twenty years, and in certain important aspects American influence was predominant, e.g. in the development, utilisation and organisation of mechanical plant. It is proposed to treat briefly the factors which affected American progress, because our position in the future is going to be in the nature of a compromise between the American and the European traditional conditions.

In order to utilise their vast and rich continent with the limited manpower available, the Americans were faced with the greatest problems of space and scale and, while they had European technical ability, they were not subject to the influences which perpetuated European traditional methods. The natural raw materials of civilisation were available in vast quantities, cheaply, and it is not surprising that three main principles were evolved :

(*a*) that large works require large efforts of either animate or machine power,
(*b*) that raw materials being cheap, it is cheaper to discard and renew than to mend,
(*c*) the necessity for action.

Even to-day it is said that America has no craftsmen in the European sense, as few things are repaired.

The first two principles have resulted in the evolution of a great range of ingenious plant units for all sorts of engineering purposes and considerable self confidence in the handling of engineering problems. The blessings of attitude (*c*), i.e. the necessity for action, are not always unmixed and it is probable that attitude (*b*), i.e. it is cheaper to renew than to mend, will require modification as the American continent becomes more saturated economically.

British constructional practice has been much affected by these influences, but we must make full use of our capacity for mental consideration if we are not to misapply their machines in our conditions.

In the following remarks I will treat briefly the development of prime movers and their applications ; of the two great constructional materials, steel and concrete ; and of a few of the more recent developments in technique and analysis.

The Steam Engine

It can be fairly said that the use of steam power for industrial purposes was well developed in this country by the early years of the nineteenth century. By 1816 there was a regular steamship service between Great Britain and Ireland, and by 1830 factories were mechanised and railways operating successfully. There was even a useful number of steam coaches on the roads before this method of transport was crushed by railway interests and a set-back in road development of at least fifty years was caused. Limitations were mainly those of constructional materials, and the history of steam engines from that period up to the present is mainly one of improvements in efficiency and detailed design accompanying improvements in materials.

No history of recent civilisation is complete without the story of the steam railways which greatly helped to make its development possible. The story of the spread of the railways does not require recapitulation here, but several other points are worthy of mention.

The railways were initially conceived as a means of transport for heavy goods traffic. The carriage of passengers soon became a lucrative adjunct, but it was not the major factor during the formative years. It was during this period, i.e. until late in the nineteenth century, that operational methods were developed, and it must be agreed that the railways were an undoubted success. By the end of the last century the country was covered with a network of tracks on which a fast and reliable service was maintained. The momentum of this successful development carried the railways on until well into the present century, but by this time, however, the conditions of our civilisation had altered radically and it seemed likely that the railways might suffer under Darwin's Law of ' Evolve or be superseded.' Population had increased rapidly and punctual passenger transport on a large scale had become a major factor in organised society. There is little value in saying more than that the railways could not fully cater for this traffic, especially in urban areas.

The difficulty can be attributed to the great operational inflexibility of the system, and while certain improvements have obtained from electrification this is not a complete cure. To survive in a modern world as a passenger carrier, improvements in at least three directions are necessary.

(1) Better technique and equipment for the clearance of breakdowns are long overdue. It is possible that frequent lay byes and passing places will be required.
(2) The block signalling system appears to to be somewhat ' remote ' for modern load intensities.
(3) The dead load of rolling stock approaches a ton for every passenger carried, which is much too high for flexibility.

All these improvements involve heavy capital expenditure, but it will either have to be spent or other forms of transport will inevitably take over.

Reciprocating steam engines, as is well known, revolutionised sea transport, and it is only in recent years that diesel engines have tended to replace the simple and cheap coal-fired steam engine, mainly on the grounds of much reduced bunker space and boiler room staff.

The Steam Turbine

Everyone is familiar with the classical turbine toy of Hero of Alexandria in 120 B.C., and since that time there were sporadic productions of similar machines making use of the reactive powers of steam. In 1784 James Watt took out a patent for a reaction turbine, and there were several others about the same period. None of them became operational, as the engineering development of the period did not allow the handling of the high speeds associated with such machines, and no real development took place until about 1884, when Parsons and De Laval produced the reaction and impulse turbines in a practical form. Since then, development has continued logically and consistently until we have now individual machines producing several hundred thousand horse-power each and probably at their peak efficiencies.

Steam turbines suffer from the same drawbacks as reciprocating engines in that the ancillary equipment for the production of steam is both bulky and heavy, and it is natural that their main application should be in relatively static positions. They have been intimately connected with the industrial generation of electricity and propulsion of the larger and faster ships, though attempts have been made to use small turbines for flexible purposes without much advantage being gained so far.

Internal Combustion Engines

Although there were earlier engines, it was not until 1860 that Lenoir produced the first really successful gas engine. This was a

double-acting machine with electrical ignition, and by 1862 de Roches had formulated the theory of the modern internal combustion engine. Soon after this, the famous series of Otto gas engines were produced. Daimler was impressed by the weight penalty involved in these engines, and in 1884 he designed a small petrol engine for use in propelling cycles. It can hardly be said that development was rapid, and there were at least two good reasons for this. As mentioned before, the early steam road vehicles were swept off the roads by discriminatory laws and practices and the early petrol-driven vehicles did not overcome this opposition until 1896. The whole value of the petrol machine was in its speed and flexibility, but fuel technology and roads were so primitive that progress was very laborious. By the time the first World War broke out, however, the petrol engine was in a position to do considerable work in lorry transport, light ships and in aircraft. Since then we have had steady improvements in materials and efficiency, and the petrol motor is now, of course, a major item in our civilisation.

Towards the end of the nineteenth century another kind of piston engine was being developed. Both Akroyd-Stuart and Diesel realised that the improved efficiency resulting from higher compressions could be logically carried to the stage when the high compression could cause the fuel to ignite spontaneously. Lower grade fuels could be used and better torque characteristics obtained. Disadvantages were the heavy weight due to the high pressures and severe vibration. Development proceeded very slowly up to the first World War though a few diesel-driven ships were in operation. After that war the momentum of development increased, and in the 1920's small high-speed diesels were under development for road transport. Their success has been so great that most heavy road vehicles are now diesel powered and the petrol engine is limited to the lighter vehicles.

Civil engineering construction finds considerable uses for engines of from 5 to 150 h.p. and, except when electricity is available, they now form the greatest part of civil engineering power units. The modern technique of large open excavations depends to a great extent on the fine range of diesel excavating machinery developed by the Americans. The bulldozer is now legendary and with its probably more useful cousins the tractors and scrapers, it is symptomatic of the American approach to their own problems of space and time.

The Gas Turbine

This prime mover is much in the news at present as applied to aircraft propulsion. Again, we must note that the initial lead dates at least from 1873 when Stoltze of Charlottenburg built a 200-h.p. gas turbine. Since then various types of experimental gas turbines have been produced, but efficiencies were low and the real development has taken place in the past few years of war in connection with air transport. In a year or so aircraft propelled by gas turbines will be in economic operation in some numbers, and it is interesting to note that this tremendous pace of development has a general application and is representative of the scientific awareness of our society to-day. The difficulties so far have been in consistency of combustion and in heat-resisting materials for turbine rotors and blades. Both have been overcome to a great extent, the former by detail design and the latter by various nickel and nickel-chrome alloys with the use of ceramics probable in the future. Immediate future development will probably be directed towards the improvement of thermal efficiencies. Just as the steam turbine superseded the steam piston engine for many uses, so the gas turbine is superseding the internal combustion piston engine for several uses, and it may be that with its advantages in fuel ancillaries it will challenge the steam turbine eventually. At present its life is too short for purely industrial processes and a technique of rapid replacement may have to be developed.

The Water Turbine

Having been closely connected with hydro-electric developments, especially for the electro-metallurgical industry, I had at one time considered giving my address on that topic mainly, but I felt that the subject was perhaps too limited in scope for the Association.

The famous water wheel which preceded the steam engine as our main prime mover is practically extinct in this country even for rural industry. This is not so over great areas of the world, and there are some countries, like China, whose rehabilitation depends greatly on the stimulus of some simple inanimate source of power.

For most industrial uses, however, several forms of turbine have been evolved to deal with various quantities of water at various heads. For high heads the main turbine is the Pelton Wheel, for medium heads the Francis Turbine, and for low heads the Kaplan which is a variable pitch propeller machine.

The turbine conception is over 100 years old, and in 1840 Boyden had attained an efficiency of 88 per cent. by careful design of an outward flow machine. Present-day

turbine efficiencies are a little over 90 per cent., and the history of these machines since about 1850 is one of improved materials, construction and control rather than of major invention. Machines have, of course, become much larger.

In this country until quite recent times hydro-electric development was a relatively small proportion of our total power output. Now the development of Highland water power has been centralised under the North of Scotland Hydro-Electric Board and a considerable number of schemes are either under construction or under consideration. As many of these schemes will be connected to a grid including steam stations, a potential operational development is involved in that schemes with little natural storage become feasible through the overall regulatory effect of the steam plant. This grid regulatory effect may also be of major importance in the great tidal power schemes like the Severn Barrage, where 2,300 million units per annum can be generated at a cost of 0·2*d.* per unit at the switchboard. The scheme envisages an installation of 32 machines giving 800,000 kw. at a total cost of £40,000,000 and could be constructed in seven or eight years. When we consider that this natural source of power is not a wasting asset nor subject to interruption, its value to the community can hardly be over estimated.

Electrical Power

Electricity is the great linking agent of our civilisation. It enables the power produced by our prime movers to be distributed and used with magnificent flexibility. It has made possible a whole host of light industries which depend on small power units for their operation, and most of our organised life is carried out by its aid. The story of the development of electrical machines is too vast to be treated here in any detail, but I will, however, refer to some of the ever widening applications of the properties of the electronic valve. It would seem, in retrospect, that the use and success of these valves in wireless work rather blinded us to their potentialities in other aspects. Fundamentally the valve is only a sensitive device for magnifying an oscillating electrical signal, and we may have been conditioned in the past to think of this signal as being always associated with the radiation of wireless waves. Within the past ten years we have seen the superseding of many mechanical methods by the use of electronic devices for all sorts of automatic controls, ranging from the temperature control of crucibles and furnaces to electronic ' brains ' for the solution of mathematical problems. Indeed, there can be very few mechanical control processes which cannot be performed much more compactly by an electronic device, though the problems of reliability and servicing mitigate against the electrical device in many situations.

Iron and Steel

It can be said that our mechanical civilisation did not attain a high rate of progress until iron and steel could be produced cheaply in large quantities, and it was not until the period 1870–1890 that the necessary outburst of metallurgical science took place. Prior to this the production of iron and steel was more an art than a science, although the famous Iron Pillar of Delhi was probably made about A.D. 300 This is a large forging of almost pure iron 24 ft. long and 6½ tons in weight. It is certainly only within comparatively recent times that any European ironmaster would have attempted such a work.

By about 1620 Dudley was producing iron by using coke in place of charcoal. In 1722 Reamur described how to convert bar iron to steel and described the cementation process for puddled iron, and by 1740 Huntsman had developed the production of crucible steel at Sheffield. In 1786 Cort was producing bar wrought iron by rolling with grooved rollers. It is quite probable, therefore, that many of the modern production methods for the metal were known before the beginning of the nineteenth century, and by 1829 the annual output of pig iron in the United Kingdom was 690,000 tons.

The production of cheap steel became possible only in 1856, when Bessemer published his blast-furnace technique and the Siemens Brothers their open-hearth method. By the last quarter of the century Sorby, with his microscopic analyses of the crystal structure of iron and steel, had made the science of metallurgy possible. At the turn of the century, steels of high and consistent quality were available, and a greatly expanded range of engineering structures became possible, ranging from the largest bridges and buildings to the smallest components.

The present century has seen the great development and production of the alloy steels, and we can now design steels to suit the individual requirements on which a large part of our civilisation is based. It is interesting to note that these problems are now so confidently handled that the heavily loaded, heat-resisting nickel steels for gas turbine blades were produced in a matter of three or four years and development still goes on. Indeed, it may be possible that we are approaching the end of the age of simple mild steel.

Light Alloys

It is hardly necessary to draw attention to the great and ever increasing usefulness of the light alloys based on magnesium and especially on aluminium. The use of aluminium and its alloys for aircraft production during the war has enabled most of the metallurgical problems to be solved, and we now see them used with great success in products ranging from suitcases, through kitchen utensils and vehicle bodies, to transmission lines. It is perhaps not so well known that the production of aluminium depends entirely on the availability of large amounts of cheap electricity, which can only be supplied by hydro-electric plants. This country was well to the fore in the production of aluminium on a commercial basis and the great plants of the British Aluminium Co., Ltd., at Foyers, Kinlochleven, and Lochaber will be familiar to many of my listeners.

Cement and Concrete

Man has, since antiquity, required some bonding material in his structures, and it is known that the Egyptians employed a good lime mortar in the pyramid of Cheops. The Greeks and the Romans had this knowledge and the Romans developed a waterproof cement or lime which would set under water for use in their tanks and aqueducts by the addition of pozzuolana to lime. In passing it may be noted that the famous Roman aqueducts which were carried straight across valleys were probably the result of their lack of knowledge of the siphon principle. It has been said that the writings of Vitruvius were at least as valuable a guide as those of anyone else up to the early part of the nineteenth century when M. Vicat succeeded in producing hydraulic limes by grinding calcined mixtures of common limes and various clays. There were, of course, various hydraulic limes being produced at this time, and by 1824 Aspdin was producing what he called ' Portland ' cement. Frost, at Swanscombe, was producing ' British ' cement, but they were both what we would class as an improved and ground hydraulic lime. Little advance was made until about 1845 when Johnston, at the Swanscombe Works, burned the raw materials to near vitrification instead of calcining them and the resulting clinker ground into the first real hydraulic cement. Development proceeded slowly, and by 1865 the new cement could show better strength characteristics than the hydraulic limes and towards the end of the century lime was ousted from large-scale construction.

The past hundred years have seen the slow but continuous development of the material by careful selection and handling of the raw materials, and the ultimate strength of a practical concrete is about 6,000 lb. per sq. in. to-day as against 1,730 lb. per sq. in. in 1852. The chemistry of the processes involved is not fully understood even to-day, but during the past forty years an ever widening range of consistent and high-grade cements have been available for constructional purposes. We can suit the setting and hardening qualities of cement to individual purposes, and the latest addition to the range is a low heat cement for use in large masses of concrete like dams and dock walls. When setting, ordinary cement emits considerable quantities of heat for several years after casting, and this causes eventual shrinkage and important secondary stresses. Indeed, some dams have had cooling pipes built into the concrete to reduce these heat effects.

Plain concrete has a relatively low-tensile strength, and about the beginning of this century a composite material of steel and concrete was evolved. The steel was placed to take up bending and bonding tensions and the design, procedure and technique was soon worked out. So successful has this reinforced concrete become that it can be used with equal facility to steel for many load bearing structures. Indeed, its capacity for being tailored to the structure *in situ* gives it many advantages.

Ordinary reinforced concrete uses only enough steel to take up the tensile stresses induced by applied loads, and there is an inherent extravagance in that the concrete below the neutral axis of bending is theoretically unstressed and only used for holding the reinforcement in position. In the past twenty years another type of reinforced concrete has been evolved to overcome this. Instead of the steel and concrete being initially unstressed, a high tension is induced during construction in the steel and the surrounding concrete placed in compression. The superimposed loads then act on this initial stress system which can be so arranged that the final conditions of stress make use of all the concrete. This pre-stressed reinforced concrete results in large economies in the mass of material used, but there are several drawbacks at present. Very high-grade concretes and steels are required and this involves a much greater degree of control during construction. The pre-stressing of the high-tensile reinforcement is not simple under practical conditions and the process has not yet achieved general use. It has, however, ever widening applications as the constructional technique is simplified.

Soil Problems

Earthworks are probably the oldest branch of engineering but it can hardly be said to

have changed from an art to a science until fairly recent times. With the establishment of the Industrial Revolution, involving the construction of canals, railways, roads, dams, etc., and all the adjuncts of an industrial society, the necessity for a fuller understanding of the qualities of the soft materials of the earth's crust became more urgent. Great cuttings and embankments involved so much capital outlay that rule-of-thumb methods of design were no longer sufficient. The earlier half of the nineteenth century was, however, the great period of refinement by experience. By 1857 Rankine had produced his paper on the stability of loose earth, and the design of retaining walls and foundations became possible under certain conditions. Unfortunately the formulæ and methods tended to be misapplied to all sorts of earth conditions including clays, and the resulting failures did not establish confidence in analytical methods.

By the latter part of the nineteenth century it was economically necessary to make use of areas of soft materials which had hitherto been avoided. Industrial society was spreading its towns and works over great areas of clayey and silty land and constructional problems were severe. Direct loading tests on those materials suffered from limitations which were not always realised and failures naturally occurred.

In the early part of the present century several important investigations of landslides and soil problems were under way, and in 1915 Bell read his paper to the Institution of Civil Engineers on the lateral pressure and resistance of clay. This was a mathematical approach and did not treat in detail the structure of cohesive materials. In the early 1920's however, the science of soil mechanics can be said to have started its rapid development stage when Dr. Terzaghi began to publish his detailed and penetrating analyses of cohesive and other soft materials. It was shown that the factors involved in clay were those of colloidal and near colloidal particles, of electro-static bonds between particles and of forces due to capillary water as well as the normal gravitational forces. Terzaghi's work was so detailed that by the middle 1930's the science was already an accepted basis of design and most major Governments had established specialised research departments.

The position to-day is that by examination of undisturbed samples of soil we can estimate within fairly close limits allowable bearing pressures, settlements, porosities, etc., of cohesive materials and we know the limits within which the early formulæ for lateral pressures are applicable. We do not know several important facts exactly, but we understand the limits and the tendencies much better.

Another branch of the same problem is that of soil stabilisation mainly in connection with road works. The fame of Roman roads becomes more than justified when we realise that it was only towards the middle of the nineteenth century that we again began to approach their standards of road construction. During the intervening 1,500 years one can only marvel at the incredible and unsolved difficulties of cross-country travel.

In the early nineteenth century McAdam developed what is now called waterbound macadam, and after another hundred years the use of bituminous materials for binding the macadam spread over the civilised world mainly because of the growing pressure of motor transport. Although it cannot be said that the arterial road system evolved in this country is very inspiring, it should be pointed out that my firm were concerned in a scheme for a motor road from London to Brighton in the early days of the century. This was to be a toll road for motor traffic only and was of railway standards in regard to grades and curves.

In other countries, however, the construction of motor roads proceeded rapidly, and there is no doubt that this, allied to our tax system, has helped foreign manufacturers to pass us in the development of motor transport.

In undeveloped countries there is always a great necessity for cheaply constructed roads, and the so-called ' dirt road ' is a very important part of their economy. There have been continued efforts over the past thirty years to achieve stable surfaces at the lowest possible cost ranging from soil cement mixtures through soil chemical mixtures to oil- or molasses-bound mixtures. The first is simply an artificial hard surface ; the second a method of controlling the moisture content ; and the third a waterproofing and binding process. Water content is the key to most soil stabilisation problems and a technique of grading and compacting has been established. The natural progression is to waterproofed surfaces where the climate is wet and many airstrips during the past war were covered with P.B.S. (prefabricated bituminous surfacing) which was simply rolled off in strips like wallpaper. In the Pacific theatre, oil, as a dust layer and stabiliser, was much used.

Reverting to the use of chemicals on soils, we are now able to charge pervious water-bearing granular materials into artificial rock by the injection of certain chemicals. This is a very useful process when dealing with excavations, as we solve both the excess water and strength problems in a single operation.

Sometimes it is only necessary to provide a relatively impervious curtain under, say, a river barrage, and injections of finely divided bituminous materials have been successful in filling the pores of natural sands.

Clays cannot be treated by any of these methods as the pore space is too small. For the same reason they drain but slowly. Clays have been hardened, and drained however, by electrical methods, and works which would have been impossible in the natural material have been carried out. The consumption of electricity is too high for widespread commercial usage at present, and, at any rate, the method has only a limited value in some types of clay.

Tunnelling is another very ancient and important form of earthwork. Indeed, its antiquity becomes quite startling when we consider the subterranean refuges, often formed in rock, into which our prehistoric forbears disappeared when threatened by danger. It is fairly certain, in Ireland at least, that this practice was the origin of a tradition of belief in pixies who could disappear inexplicably. No doubt these early men knew how to crack rock by alternate heating and quenching with water, just as the Romans certainly knew, and indeed the method is still in use in some quarrying operations to-day.

A roadway tunnel through the Alps was started though not completed as long ago as 1450, but we can say that modern tunnelling practice is largely the outcome of the accumulated experience of the past hundred years or so.

A century ago black powder was the only explosive used, but it has now been entirely superseded by gelignite or similar high explosive. Liquid air has been used, but generally in surface work only, as there are disadvantages involved in its volatility. At that time, also, handwork was used in drilling and clearing, haulage was by man or animal power, lighting by oil lamps, and ventilation fortuitous. It was in connection with the Mont Cenis tunnel that power drills were devised and first used in 1861, and the great physical difficulties involved on other Alpine tunnels provided a great forcing ground for the refinement of tunnel technique. To-day the tunnel is well lighted and ventilated during construction, whilst rapid drilling with pneumatic drills, clearing by mechanical diggers or scrapers and mechanical haulage are all arranged in a co-ordinated effort which tends to rapid progress and economy.

When we consider tunnelling in soft ground we meet another range of problems. Generally the walls, roof and sometimes the floor have to be supported by various methods like timbering, lining with brick, concrete, cast iron, or steel. When water troubles are experienced the work can be carried on in compressed air or by consolidation of the material artificially as mentioned before. In many cases the use of a shield at the working face is either necessary or economical.

The first shield was patented by M. I. Brunel in 1818 for use in the construction of the first Thames tunnel, which must rank as a major engineering achievement considering the difficulties involved. The next shield was designed by Greathead for the Tower Subway, and this was the prototype for the modern shield which can cater for a considerable range of earth conditions. With a modern shield and mechanical excavation a 12 ft. Tube tunnel in London Clay can be advanced by as much as 160 ft. per week.

Harbour Works

When we recall the Mole and Pharos at Alexandria and the layout of some other classical harbours we realise that the historical maritime civilisations of the Mediterranean had available a great measure of technical ability. Indeed, there is some doubt as to whether the intervening period up to about the eighteenth century was one of progress at all. Men had continued to off-load ships on to shores or small wharves and commerce was so small that there was little urge to do otherwise. By the early eighteenth century, however, commercial maritime transport was growing in importance and wet docks were becoming a necessity. A slow steady progress was maintained, with wharves and port ancillaries growing larger as the size of ships increased. Up to the end of the last century much of this work was carried out in the traditional cyclopean masonry, but with the development of concrete this form of construction became modified in many circumstances, as the walls could be cast *in situ*. The use of reinforced concrete in place of the traditional timber enabled heavier jetties and wharves to be constructed, but development was really only in the increased scale of works. In the present century we have seen a number of interesting changes, for example, in the development of steel sheet piles which enable wharves to be built with considerable speed, in the development of iron screw piles into steel screw cylinders with greatly increased range of usefulness, and in the development of constructional technique like the well-point system of ground water lowering.

The recent war saw a great increase in what is called prefabrication. This can be defined as the practice of partially fabricating structures in the shops so that they may be

assembled rapidly at the final location. The idea is not new, nor is it always economical, but the scale on which it was practised during the war is certainly new and may affect certain changes in peace-time construction.

The story of the invasion harbours is too well known to repeat here, though they were the crowning achievement of prefabrication. Less publicised were the permanent wharves for the heaviest loadings which were built in some of the Scottish sea-lochs. These were built by screwing down steel and concrete cylinders 3 ft. in diameter into the bed of the sea and then placing a prefabricated concrete deck on top. Speed of construction was considerable and the wharves handled a large part of the U.S. armed forces entering this country.

Further south, large forts complete with guns were built in dockyards and floated out to the required sites in estuaries where they were sunk in position to form fixed strong-points.

Models and Experimental Analyses

With the ever increasing complexity of the technical demands of society we have had to handle problems which are either not susceptible to mathematical analyses or only laboriously and impractically so. In consequence we have developed analysis by experimental methods to a considerable pitch. For direct stress measurement the electrical resistance strain gauge has been much used recently for a wide range of problems. When we have to consider internal stresses in structures the practice of photo-elastic analysis is of great value. As long ago as 1816 Brewster noted that strains in crystals affected their optical properties, and since then the effect has been developed into a process in which scale models made from a clear medium like celluloid are stressed and analysed by polariscope. In the main only two-dimensional problems are considered, but three-dimensional analyses can be carried out within limits. Though it cannot be said that photo-elastic methods are either simple or flexible, they have been our only practical approach to many problems. More recently, Professor Southwell's relaxation methods of mathematical analysis have proved useful in a great range of problems.

Another great field of experiment is that associated with fluid dynamics. Aerodynamics is now one of the major sub-sciences, and its success can be gauged by the fact that very few aircraft failures to-day can be traced to poor aerodynamic design. Much of the research effort to-day is directed towards the piercing of the sonic barrier, and, though we have reached velocities approaching that of sound with conventional aircraft, the next step will depend greatly on wind-tunnel models and probably as much so on free flying models, fitted with automatic recording and transmitting apparatus. In civil engineering the importance of aerodynamics is not so great, but the recent failure of the Tacoma Narrows suspension bridge in a 30 m.p.h. wind has heavily stressed the necessity for aerodynamic investigation in cases where structural oscillation can occur.

Hydrodynamics has probably greater capital importance even than aerodynamics, and as long ago as 1872 Froude carried out his famous work on the resistance to motion through water. Since then the use of scale models has produced great improvements in hull forms, from barges to the largest liners. More recently it has been possible to represent the behaviour of vessels by self-propelled models and, indeed, the technique is now so refined that it is of value in arbitrations as, for example, in the case of the collision between the *Queen Mary* and H.M.S. *Curacao*.

Much of the handling technique as well as design of components for the invasion harbours was worked out in laboratory tanks with consequent saving in the time required to instruct service personnel in their use.

One of the great commercial marine problems is that of alterations in existing regimes, e.g. silting and erosion. For this purpose a model concerned with improvements to the Garonne was constructed as long ago as 1875. The first really scientific models, however, were built by Professor Reynolds at Manchester University and Professor Gibson's model there twelve years ago in connection with the Severn Barrage is now classical. By a suitable choice of scales and materials it was possible to reproduce seventy-eight years of the history of the estuary closely and by inference the future can be foretold. Several models have since then been constructed for various estuaries, ports or rivers in all parts of the world with considerable success.

A new laboratory under the direction of Sir Claude Inglis is being set up in this country by the Hydraulics Research Board of the Department of Scientific and Industrial Research, and one of its first works will be a new model of the Severn Barrage, as the lay-out has been changed since Professor Gibson's model was in use, and local re-arrangements to the flow at the barrage will take place.

In the construction of dams one of the more important aspects is the disposal of flood water over or around the structure. When we consider that even a medium catchment area in this country can produce several hundreds of tons of flood water per second a considerable amount of energy has to be

dissipated if the water flows over the crest of the dam, which may be upwards of 100 ft. high. Where sound rock occurs near the surface, the solution is simple, but where this is not so, considerable excavation for spillways may be necessary, and economy in design becomes very important. Models in laboratory conditions are very useful for this purpose and refinement is such that costly remedial measures after construction are no longer justified. By a suitable arrangement of slopes and sills we can make the water itself do most of the work—the kinetic energy being changed to potential energy in the form of depth.

Similar model methods can be applied to a great range of hydraulic problems ranging from erosion at weirs and bridge piers to the silting of canals and the prevention of dangerous ice jams in intake ponds.

The subject of my address is very wide, and in the short time at my disposal I have only been able to touch on some aspects of it, and not in any way comprehensively. I hope, however, that what I have said will give some indication of the great progress which has been made in engineering science, and it is my belief that this progress will continue.

SECTION H.—ANTHROPOLOGY

THE ANTHROPOLOGICAL APPROACH IN SOCIAL SCIENCE

ADDRESS BY

PROF. DARYLL FORDE, PH.D.

PRESIDENT OF THE SECTION

WHEN you did me the honour of inviting me to preside over the Anthropological Section at this first post-war meeting of the British Association and I considered the subject on which it would be most appropriate to address you, I decided, for a number of reasons, that it would be desirable to attempt some indication of the rôle of Anthropology in the development of Social Science. Some of the most substantial of recent contributions in Anthropology lie in the sociological sphere; but the cessation of conferences during the years of war and, in particular, the interruption of the annual meetings of the British Association, which have provided so valuable a forum for the exposition and exchange of ideas among workers in the various specialist fields of science, have been unfavourable to any assessment of the extent and significance of progress in Social Anthropology. Still more important, perhaps, the British Association itself has recognised, in the creation of a special division for the Social and International Relations of Science, both the need for studying the relations of scientific advance to social problems and for the scientific study of society itself. It seemed to me, therefore, timely to attempt to present some account of the Anthropological approach in Social Science. Obviously in a short address it is only possible to sketch some broad outlines and to present a few illustrations, but I hope it may prove useful to indicate, however briefly, the relation of sociological problems to anthropological studies and the ways in which anthropological methods and concepts have been developed in the attack on them.

As a study of the collective characters and activities of mankind, Anthropology has by tradition been diverse both in its approaches and in the variety of its problems. On the one hand, it has been directed towards the understanding of the physical diversity of mankind. This is the approach of evolutionary biology with its concern for the evidence of the occurrence and causes of the evolution and diversification of human varieties. At the same time, it has sought to discover and understand the cultural diversity of mankind and to unravel the vicissitudes of cultural development of human groups. In this field there is first the direct interest in the actual cultural history of mankind comparable to the palæontological and taxonomic interests in the biological sphere. But the attempts to evaluate the various factors which account for the particular features in any given culture and of cultural change through time has inevitably led to inquiry into fundamental and universal processes which, operating at variable intensities and in differing combinations in particular situations, account for the actual character of particular cultures.

At the same time, the comparative study of diverse cultures and of their biological and environmental contexts affords the means whereby the existence and operation of particular factors may be determined. In other words, the variety of human cultures affords a laboratory in which, through the comparison of differing forms and their contexts, particular processes can at least in part be isolated for study. This last is the more strictly scientific or analytic approach with some aspects of which I shall be mainly concerned to-day.

The term science is often loosely employed with a wide variety of meanings and, while there is no opportunity to-day to consider the matter at any length, it is necessary to recall both the essential character and objectives of scientific study and their relation to other modes of knowledge. Science, properly speaking, is a mode of investigation directed towards the discovery of processes of universal application with regard to a relevant field of phenomena. Its method is essentially analytical, it seeks to disclose the properties or attributes of classes of phenomena and

the causal relations between them. These it formulates by means of definitions and rules which embody these properties and their interconnections. Everyone is familiar with such rules or laws in connection with the elementary principles of physics or chemistry that are part of general education, but the relevance of this mode of analysis is frequently ignored or misunderstood when human actions are involved. In consequence, the implications, which are of fundamental importance, for any science of society, are often lost sight of. Of these, the most important is firstly that a particular scientific analysis does not seek to account at one and the same time for all the characteristics of any concrete situation or a series of such situations. Selected properties are isolated for study in relation to others that may be found to be functionally interdependent with them.

In human affairs the direct and comprehensive interest in the concrete situation, whether it be a general pattern of social organisation, certain forms of beliefs and ritual practices, or a technique whereby artifacts are produced and employed, leads to provisional explanation in terms of integrated description. That is to say, a very wide range of known conditions and processes are reviewed and their contribution as determinants of the concrete situation is qualitatively expressed. This is the essence of the historical approach to understanding, an approach which, contrary to common misconception, does not mean an approach merely in terms of time or an explanation in terms of chronology. Time and the measure of its lapse by means of chronology is significant in history because it is one of the coordinates of the phenomenal world, but space is of equal significance and the expression of spatial relations are equally prominent (1).

But what it is fundamentally important to stress here is that integrated descriptions of this kind are dependent on science. In the first place, no statement of this kind, that is, no explanatory account of how things come to be as they are in a given field of space-time, is possible without postulating and employing for explanatory purposes certain properties and rules of relations already assumed to be applicable to the phenomena in question.

Thus an account of a particular political organisation such as an African chiefdom or the British constitution at any phase of its development involves, in fact, assumptions concerning rules or uniformities applicable to the political relations exhibited by man in society. It may, for example, be assumed that the scale of political organisation is dependent on such factors as the physical and technical facilities for intercommunication and that changes in the latter will tend to changes in political scale. It may similarly be postulated that interests arising from occupational activities within the economic framework of a society will be reflected in its internal political structure such that increases in the economic power of any section of the community as a result of technological changes or the reduction of earlier restraints will tend to be accompanied by changes in political structures whereby the interest of that section secures an increment of political authority. The point to observe is that descriptive studies of particular social conditions or developments, whether they be what are commonly regarded as historical studies treating social and cultural developments over considerable periods of time, or ethnographic descriptions of very limited time depth, and whether they be wide in the range of activities and institutions considered, embrace a great deal of the life of a people, or whether they be confined to the portrayal of a particular institution, depend always for the interpretation of the particular events and their interrelations on the assumed validity of manifold general principles assumed to underly the social behaviour of man. In fact, historical or descriptive studies are a species of applied science. Just as the various branches of engineering depend on the postulated uniformities of physical sciences, and modern medicine depends for diagnosis and therapy on the application of the concepts and principles of biological sciences, such as physiology and biochemistry, so the analysis and description of particular cultural situations presuppose principles concerning human behaviour. Not a line of human history could be written without such assumptions. Some body of theory concerning the cultural behaviour of man is implicit in every attempt at integrated description of the activities of human groups. The theories and the concepts which they employ may be vaguely formulated, they may not be explicitly stated, but conceptually they are of the same kind as those of natural science. The fact that they may be vague, that their verification is weak, that they may even be shown to be fallacious, or that when they are made explicit they appear to be part of common knowledge, is irrelevant to their status in this respect.

I should call attention here to another point of fundamental importance, namely, that practical activity in human affairs, the formulation of policies, the practice of administration and individual conduct in society similarly involve hypotheses of social action. The politician's estimate of the attitudes of his constituents or of the public

at large to some particular measure of legislation ; the action of a leader in directing a team, the estimate formed of the capacity, worthiness or usefulness of an individual in connection with an activity, all these in large part depend on what we commonly refer to as experience and judgment. But experience and judgment in practical affairs are the expression of hypotheses concerning regularities and interrelations in human behaviour, in other words, of theories concerning the social nature of man.

Here it may be objected that it is preposterous to raise to the level of scientific theories the vague, half conscious and all too fallible assumptions implicit in practical judgments. But this is to misconceive the nature of scientific theory. A scientific theory is, as I have already emphasised, a hypothesis, the most satisfactory hypothesis available at a given time from the points of view of verification and comprehensiveness, concerning the properties of certain natural phenomena and their interrelations. The theories or laws of physics and chemistry differ in degree, in degree of explicitness, precision and verification, but not in kind, from hypotheses concerning processes in human society. This difference in degree may be and often is enormous, and the reasons are not far to seek. As we pass from inorganic to organic, and from organic to social phenomena, the complexity and variability of the phenomena and of the factors involved in determining their properties, as well as the extent to which these can be isolated for examination and the difficulties of securing observation under requisite and known varieties of circumstance, are all greatly multiplied. Where as in the study of the social relations of man, the variable factors that in combination determine any section of the pattern are so manifold it is not surprising that hypotheses are, as compared with those in physical science, crude or limited in reference and are so much more difficult of verification and precise expression.

But such hypotheses are a condition of logical thought about social life, and since belief and action in this field are, as a consequence of man's self consciousness, paramount human interest, their formulation and critical examination are of unique importance. Current among every people there are hypotheses as to the processes controlling their cultural activities and their social relations. Everywhere these theories are factors in their explanations of the events that befall them as a community and of their judgments as to the practical courses they should pursue. We have lived in a period when crude and demonstrably fallacious hypotheses ascribing unalterable biological foundations for unverified cultural aptitudes and social tendencies to particular peoples have been accepted as official doctrines of a powerful state. The so-called ' racial theories ' of Nazi Germany were hypotheses concerning alleged factors in the social process which were accepted by millions and provided a foundation for historical explanations and the acceptance of political actions which have devastated Europe and impoverished the world. That these particular hypotheses, like hundreds of other sociological myths that have strewn the pages of historical and political writings at all periods, could be shown to be fallacious, does not affect the fact that the particular cultural and social conditions in which men find themselves are interpreted, and indeed can only have meaning, in terms of theories of society.

From this follows the paramount importance of the endeavour to subject social phenomena to the inductive analysis and the critical testing of hypothesis which are the canons of science. That this is a task of very great difficulty where the data are so complex, and the variables so numerous and so difficult to isolate, where the investigators themselves are inevitably entities in a social system, and so especially liable to emotional attachments, is not to be denied. But it is here that the anthropological approach can perhaps claim some merit as one conducive to a detached attitude to social theories affecting one's own group and period. For the anthropological tradition has in the first place emphasised the need to consider particular problems within a framework embracing the human species as a whole. Whether it be economic organisation, religious belief and practice, or political institutions, the anthropologist eschews hypotheses of special creation concerning particular human qualities of vice or virtue, or of the divine providence of ethnocentric deities, Thus a practice such as shamanism, whereby phenomena of psychic dissociation are interpreted as spirit possession and utilised according to a set pattern in the alleviation of social crises, is not approached by the anthropologist on the assumption that peculiar and occult powers are the special qualities of certain peoples, scattered through the world. Every instance provides material towards determining by analysis of each and comparison among them of the range of conditions in which these phenomena of dissociation are stimulated and institutionalised.

Similarly, the occurrence of slavery in many societies is not ascribed to the especial brutality and cupidity of particular groups within the human race. A comparison of forms and contexts shows that the degrees

of subjection established with legal sanctions and social approval range from the mildest of enforced adoption to the maintenance of slave gangs devoid of social status. We are dealing not with a single thing—' slavery '—nor with a single process due to a simple cause, but with a wide range of social phenomena which have certain formal criteria in common, and are resultants of a number of concomitant factors operating at exceptional intensities in particular societies. Comparative study of the social character and context of subjection reveal, as Siegel (2) has recently shown, that there is effective economic or political inducement to the enforced control of human beings of extraneous social origin over only a limited range of technological and ecological conditions. Still more limited and distinct from one another are the characteristics of the several contexts on which there is inducement to such variants as pawning, enforced adoption of captives, domestic servitude, and chattel slavery. Chattel slavery in the Classical World, in the New World plantations, and the indigenous slave colonies of some West African societies were responses to facilities for comparatively large-scale production and commercial exchange where manual labour was a scarce and limiting factor. Very different are the social character and economic conditions of agrarian serfdom in self-subsistent local communities, whether of Medieval Europe or of chiefdoms in East Africa and the Sudan, where the division of labour is slight and the units of surplus output are small and dispersed. Other forms of subjection do not seek economic advantage. The domestic servitude of captives practised by many peoples in Africa and the New World are rather dependent on the tendency to assimilate the captive and increase the numbers of the kin or local group for its political aggrandisement within the wider community.

I have given these brief illustrations to show that for the anthropologist, the customs, beliefs and patterns of intercourse among a particular people are but one picture in the vast gallery of the ever-changing cultural activity of Man. In the study of any aspect of a particular culture he seeks in the first place to delineate its character, its qualities and interconnections. But he is also challenged to dissect from it the operation at particular intensities determined by both bio-physical and the wider cultural context, the multifarious processes that are the universal determinants of culture and social organisation.

Secondly, it may be claimed that Anthropology has, in its concentration of attention on the cultures of non-European peoples, been less liable to emotional distortion in its approach to description and analysis. Although exceptions could no doubt be cited, the anthropologist, in his appraisals of cultures and social systems, has been comparatively free from the passions underlying historical apology or of the polemics of social struggle. He has remained substantially outside the society which he has studied; its values have not permeated his own to the detriment of accurate observation and recording. Indeed, his very difficulties in securing and presenting reliable data, and in discovering coherence among them, spring in large measure from his lack of prior attachment. He may grope uncertainly for the determinants of the social phenomena he observes, he may be baffled to analyse in adequate categories the ideas and customary actions he encounters, but he is at least assisted by his detachment in distinguishing between observable event and indigenous rationalisation.

The anthropological outlook with regard to social science may therefore be said to be characterised by two complementary approaches. On the one hand, it seeks to determine the structure of social relations among any given people in terms of a comprehensive observation of their cultural norms. While it may be necessary for practical reasons or in the pursuit of some particular problem to concentrate on some aspect of the culture or of social relations, particular institutions are not divorced from the total cultural context, nor is the social structure described and analysed only in terms of the ideal patterns or vitiated by acceptance of the rationalisations of the people themselves. In short, the anthropological aim is to determine and interpret social systems in terms of comprehensive ethnographic data.

On the other hand, the anthropologist views any given society as one exemplification of general processes whereby aggregates of the human species cohere in response to the physical condition of their habitat and to their psycho-physiological drives as organisms. His analysis of any one community is informed by the need to present data that are significant and accurate for subsequent comparative studies. And in these comparative studies he seeks through the detection of concomitant variations both within the social structure and between it and the external environment or the organic conditions of the population, to isolate abstract but recurrent properties inherent in a range of concrete behaviour whose functional dependence on other properties of the social system or on bio-physical determinants may then be determined.

It is necessary to recall here, however, the

very wide range of processes that are involved in determining the collective activities of any group of people. The physiological and psychological qualities of individuals are variable, and so in the aggregate will be those of any given groups, and both general and special characteristics in this field are significant determinants. The understanding of the significance for culture of physiological and psychological processes and of their variable incidence is obviously dependent on the advances made in these sciences by their own methods. This is but an instance of the familiar interdependence between different fields of science, but is deserving of emphasis. Every branch of science makes assumptions and employs concepts the validity of which depends on the findings of sciences at more basic levels. And it is important to remember that any analysis of culture makes physiological and psychological assumptions and that in cultural studies there emerge problems which depend for solution on investigations in those fields. Secondly, the conditions of the habitat and of all the natural resources which are drawn upon in the life of individual and group will affect the modes of activity in that life. But the effects of the psycho-physiological and environmental ingredients in the immensely complex equation are also secondarily modified at any time by an existing cultural pattern, so that one may have to reckon with differences in their short and long run effects in view of the effects of cultural inertia. Furthermore, within the cultural field, different sectors or categories such as technology, economics, political organisation and cultural values are interdependent in the sense that changes in anyone will have effects on the others, while each is sensitive in varying measure to changes in the external world.

This approach to social analysis owes an immense debt to Herbert Spencer, who insisted not only on comprehensive analysis of all the factors involved in the determination of a particular social situation, but also emphasised and illustrated the importance of comparative methods for the elucidation of the factors and the abstract formulation of processes underlying the concrete behaviour of man in Society. Spencer also stressed the great value of data from small-scale societies in which the totality of the system could more readily be grasped and analysed. His addiction to the use of ethnographic evidence from 'primitive' or small-scale societies has often been criticised by later sociologists who have seen it as a wasteful or irrelevant deflection of attention from the data and problems of modern industrial societies. But Spencer appreciated, as did Durkheim, Hobhouse, Sumner, and others whom he so strongly influenced, that for the discovery of underlying process by comparative methods, it was necessary not only to consider a wide range of social forms and contexts, but also to begin analysis with material that is comparatively simple from the structural point of view.

It is, of course, necessary to distinguish between Spencer's conceptual framework and the details of his methods and use of ethnographic data. The first as set out in the opening chapters of his *Principles of Sociology* (3) can hardly be bettered to-day as a comprehensive statement of the scope of social science and of the general connections between the physical, biological and cultural phenomena involved in its study. He formulated with admirable comprehensiveness the scientific validity and methodological importance of empirical study of social morphology and social function, and of the comparative method for isolating and estimating the effects of the various factors determining particular features of morphology and function.

On the other hand, his actual procedures in investigation, dominated as he was by the desire not merely to demonstrate the validity of an evolutionary hypothesis, but to establish the actual course of the social evolution of mankind, suffered from grave defects which vitiated social theory and much of the work in Anthropology itself for many years. By introducing *a priori* stages of evolution which captivated the imagination and diverted the attention of anthropologists for two generations, he substituted for the comparative study of actual societies which he advocated in principle, the formulation of hypothetical social conditions in imaginary primeval societies which could be considered plausible starting-points for processes of unilineal evolution by which the more complex historic societies have emerged. This was particularly glaring in his treatment of marriage and the domestic family, where attention was focused not on the need for exact study of the morphology and function of the marital group, but on a vain endeavour to substantiate from defective ethnographic data a purely speculative evolution from promiscuity through polyandry and polygyny and marriage by capture to the monogamous family of 'higher' civilisations. A further defect, which sprang in part from this *a priori* bias, allowed him to be comparatively well satisfied with the sketchiest ethnographic material. Although, as has been said, he provided in his theoretical framework of sociology an admirable conspectus of the character and mutual interdependence of the many factors contributing to the determination of social form and emphasised the need for their consideration, both in attempting

to understand any given society and in accounting for the differences among them, he failed to stress the need for intensive and specialist investigation of societies comparable to the morphological and physiological studies of the biologists in order to obtain the data which would make such analysis possible.

Thus, although Spencer fully appreciated the importance of comparative study on the widest scale in order to determine generalisation of validity for all human societies and, in consequence, made great use of ethnographic evidence and devoted much energy to promoting the compilation of a corpus of ethnographic data for the express use of his successors, it was not he, but those who were later compelled to undertake the task of demolishing *a priori* evolutionary dogmas, who demonstrated the importance of the meticulous examination of the particular forms of social life in order to determine morphology and functional relations in any given society. It is to the pioneers of intensive ethnographical field work, to Cushing, Bourke, Boas, Kroeber and Lowie in the United States, and to Rivers, Radcliffe-Brown and Malinowski in this country that we owe the development of more exact methods of investigation and analysis, whereby the nature of the forms and the essential character of the processes and their conditions can be adequately presented for the comparative study which Spencer so rightly saw was indispensable both for a scientific theory of society and for explanation of the occurrence and interconnections of the specific features of social structure in any particular society.

By way of illustration of the manner in which detailed and comprehensive ethnographic investigations and the comparative studies which these render possible have advanced our understanding of the determinants of social structure, I will consider briefly some aspects of the character and rôle of kin groups in social organisation. The tendency for rights and status in any community to be transmitted to succeeding generations on the basis of kinship is a fairly obvious function of parentage and can be shown to affect succession in all human societies. But one of the problems which confront any students of the rôle of kinship in social organisation is the great variation in the extent to which this tendency gives rise to corporate groups of kinsfolk within and between which a great part of the social life is organised. The ethnography of a sufficient number of societies of different type is now known with enough precision to make possible not only preliminary determination of the variable relations of such groups to the wider social framework, but also for analysis of the functional dependence of their development and decline on more fundamental cultural variables.

Where, as a result of limiting conditions of the habitat and of the techniques for essential production, the stability and density of population is low, we find a class of societies exemplified by such peoples as the Andamanese, Eskimo and the aborigines of the Great Basin of Western North America, in which the local community is a small unstable aggregate of domestic families, a dozen or less in number, which has equally unformalised relations with neighbouring communities sufficient only to maintain cultural homogeneity as expressed in language, techniques, cosmology and ritual. Detailed and systematic analysis of the social structure of such communities as, for example, that of Radcliffe-Brown on the Andamanese (4), of Boas, Rasmussen and others (5) on the Central Eskimo, and of Lowie, Kelly and Steward (6) and others among the Basin Shoshoneans, have shown that the normal sentiments of solidarity and mutual obligation between parent and child and between siblings which are generated by prolonged interaction in the domestic unit, are clearly manifest that the usual extension through secondary links to collateral kin underlie the prominence of kinship links in maintaining cohesion between the component families of the local group and in determining the intergroup movements of particular individuals and families.

But the poverty of the habitat, the rudimentary character of productive techniques, or the combination of both, so severely limit the scale and stability of both separate settlements and of the wider community, that the tendency for the permanent attachment of a regulated body of persons to an aggregate of fixed resources has little opportunity for expression. The establishment of specific rules for the transmission of collective and individual rights in the control and exploitation of resources is likewise inhibited. The food supply in any locality, whether it be a harvest of pinyon nuts or wild grass seeds, among the Paiute or the seal population at winter and spring hunting grounds, and the caribou herd migrating through an inland valley among the Central Eskimo, is so unpredictable or so widely scattered that the tendency for particular kinsfolk in any generation to form coherent exclusive groups are frustrated by the opportunism enforced on the individual and the household by the ecological situation. Systematic organisation through rules governing the residence of families, the affiliation of individuals to groups and succession to status or economic rights in accordance with descent, is lacking because the ties latent in parentage and

siblinghood are prevented from formalised expression in the social organisation.

Where the combination of available resources and exploitive techniques reach higher levels, the stability and size of local groups and the regularity of interaction among them all tend to increase. In such societies, the fundamental tendency to transmit rights and status from parent to child and for them to be shared among siblings of one or other sex, has wider scope. In combination with the equally fundamental dichotomy of the sexes in economic and political rôles, this leads to the emergence of more stable groupings of kin according to a principle of unilineal affiliation. Thus groups of unilineal kin may collectively identify themselves both practically and symbolically with tracts of territory they occupy, exploit and seek to defend, and place high value on their condition of mutual obligation and their internal coherence with reference to outsiders.

There is no lack of well documented demonstration of the process whereby the individual on reaching maturity in many such societies derives from one or other parent, and sometimes severally from both, membership in a unilineal group of kin with rights of residence, and participation in its collective life. This includes, in particular, a share in the exploitation of resources controlled by the group to which the parent belongs, and the enjoyment of that status in the wider community which may be associated with the group as a persistent segment of society.

But the scale and degree of formalisation of groupings based on unilineal grouping of kin is highly variable. Equally variable, and often according to the complexity of the culture, is the degree to which the various elements of social status and of rights and obligations are specialised and distinguished one from another. In some societies unilineal succession and the sphere of operation of groups of unilineal kin may be restricted to limited sectors of the social process. The transmission of particular rights such as residence, the use of specific resources, the ownership of movable goods, the assumption of honorific titles or the practice of magic, may be divorced from one another and some only subject to rôles of unilineal inheritance. Indeed the duality of parentage and the differentiation in the procreative, domestic and economic rôles of males and females sets up opposed tendencies to patrilineal and matrilineal transmission and grouping. Limitation of space makes it impossible to inquire here into the significance of the growing evidence for the persistence and importance for social structure of both tendencies. It is clear, however, that while one line of descent often confines the other to unformalised and inter-personal spheres, and once established tends to pervade the social structure, it is nevertheless more common than was formerly supposed for both to receive formal expression over different fields of social organisation (7).

To return, however, to less complex situations; in some instances a simple relation is obvious between collective control and organisation by a group of men of tracts of hunting, fishing or farming territory, and the transmission of membership in that group to their sons, a situation well exemplified on a small scale by the family hunting territories of the Algonkian studied by Speck (8), and by the dominance of patrilineal continuity in membership of the winter camp groups among the Blackfoot described by Wissler (9). Transmission in the opposite sense by women to their daughters is also recorded in rudimentary form as, for example, among some Australian aborigines in Queensland, where rights to the exploitation of wild yam patches are transmitted matrilineally among women.

I recall and illustrate these well-known tendencies not because I wish to suggest that there is a simple and always readily discernable relation of immediate cause and effect between current modes of food production and division of labour on the one hand, and kin-group organisation on the other. On the contrary, uneven change and cultural inertia may give rise to considerable discordance between them which can persist for considerable periods. I wish to suggest only that when a comparatively low threshold of stability and density of settlement is reached, tendencies for unilineal transmission of both individual and collective rights, giving rise to the formation of unilineal kin groups, emerge spontaneously from the conditions of the economy in consequence of the operation of two general processes—parent-child succession and the sex division of responsibility for the provision of economic needs. Incipient organisations of this type may, as in the case of the patrilineages discovered by Gifford (10) among the Miwok and other peoples of Central and Southern California, receive little or no formal recognition or expression in social symbolism.

The elucidation of factors tending to produce both unilineal transmission of rights and status and groups of unilineally related kin are, however, but the starting-point of any interpretation of the wider phenomena of clan organisation. It has already been recalled that, below a certain level of scale and stability, this type of organisation does not emerge. Moreover, as has been said, any comparative survey shows that the scale, the

degree of formalisation and the functional importance of organisation is highly variable. There is a great diversity in the numerical strength of major unilineal groups, in the number of such groups in the community, as well as the degree to which the major groups are segmented into sub-divisions in a descending order. Thus, a few hundred people in a single Hopi Pueblo may be divided among nearly a dozen matriclans, each counting only some twenty adult males (11). But each is a fully corporate and exclusive group with regard to house sites and farming land and a distinctive segment in the organisation of the community for ritual purposes. At the other extreme, the major unilineal groups, as among some African peoples, such as the Akan peoples of the Gold Coast or the Baganda and the Nuer, may each run into more than a thousand members. Even small localised clans, the majority of whose members are in frequent and direct interaction, are commonly found on investigation to be segmented into component lineages consisting of kinsmen descended from one ancestor, only three or four generations back. Thus the Hopi clans are aggregates of still smaller lineages, and both ritual prerogatives and authority within the clan as a whole inhere in one on grounds of traditional seniority. Where major unilineal groups of larger scale occur, it is found not only that there often is segmentation at a series of levels, but that with respect to the transmission of rights and duties, the more specific the claim or obligation, the narrower the segment involved. Even admittedly inadequate material on the Iroquois makes it clear that the basic unit of economic, political and ritual organisation was not the large non-territorial and exogamous matriclan, but their component unnamed matrilineages, certain of which had established rights of nomination to clan and tribal offices (12).

Fortes' (13) recent analysis of lineage structure within the clan organisation of the Tallensi has demonstrated in detail both the extent of this segmentation and its functional relations to succession and the organisation of effective groups for both practical activity and ritual. It has also confirmed Evans-Pritchard's finding that lineage segmentation, as studied by him among the Nuer, is a function of opposition of sub-groups within a wider unity (14).

Intensive field studies, in which the formal concepts of social organisation employed by the people themselves have been analysed in relation to the actual composition of groups as revealed by genealogical and census data over a sufficient sample, have also shown how the proliferating unilineal kinship ties, which are being continually created afresh with each parent-child sequence, tend on the one hand to produce segmentation of sibling groups and on the other hand permit a wider social cohesion among the spread of collateral kin.

The dispersed clans commonly found in large ethnic groups do not consist of an undifferentiated aggregate, in which, for any purpose, one clansman is socially identical with another. The members are not dispersed as individuals, but in small lineages, the descendants of a common grandparent or great-grandparent. These minor lineages, not the individuals, are the essential units within a dispersed clan. Thus, Dr. Richards reports that the dispersed matriclans of the Bemba are made up of 'houses,' each comprising the direct descendants of a recent ancestress three or four, or, at most, five generations from the active adults, and that it is within the 'house' that the unilineal transmission of status, rights and duties is normally confined, whether it be the inheritance of goods, the succession to a chiefship or ritual office, or the fulfilment of an obligation (15). Similar small lineages of close kin are also shown to be the essential units of social continuity and the vehicles of social replacement within the dispersed patriclans of the Nuer. The same essential functions have been found to attach to small lineages of three to five generations in depth as part of the unilineal structure of larger clans as a result of recent studies smong the Ibo and the Yakö in S.E. Nigeria, and the Ashanti in the Gold Coast (16). In seeking to understand the significance of unilineal organisation, it is on this unit that attention should be focused; for this is the group which, in the frequent and direct interaction of its living members, in the strength of the sentiment of common descent from a clearly remembered ancestor and in the uniformity of numerical strength, is common to so many and otherwise various social systems. It is a body of persons linked by siblingship or parallel cousinhood, up to the third degree, which appears to represent a recurrent adjustment to the scale of co-operation and mutual aid elicited under stable conditions of small-scale production.

Having found that what may be termed the basic lineage, with a depth of three to five generations from living adults to the apical ancestor, is so widespread a feature of unilineal kinship organisation, we are in a position to consider groupings more extensive and variable in scale in terms of their relation to this basis unit. In some societies, of which the Hopi and the Yakö may be cited as examples, the wider unilineal organisation consists of simple aggregates of a few such

lineages. But there are also societies in which a considerably more elaborate structural relation between the basic lineages is maintained in terms of real or alleged genealogical links. A number of basic lineages which rank as distinct and opposed groups in one social context are in another merged as a single group in opposition to one or more similar groups of this order which are likewise segmented with regard to more particular rights and duties. And this process of aggregation in balanced opposition is found to hold through further stages, being effective in some cases right up to the total membership of the clan. In other words, the aggregate of clan membership is found to be successively segmented with regard to action and sentiment into a series of groups of decreasing genealogical depth so that one can, as does Fortes, speak of maximal, major, minor and minimal lineages among the members of each of which a sense of solidarity is evoked in particular situations. This relativity in lineage structure within large clans has been reported by Evans-Pritchard for the Nuer and by Fortes for the Tallensi, and a similar structure can be inferred from less systematic data for the Ibo and the Ashanti. It will doubtless be revealed in the future as a distinctive feature of the social organisation of other peoples in which there are descent groups of large scale.

What are the factors which determine the extent to which lineage organisation, which is confined in some instances to what may be called the basic lineage of siblings and close cousins, being elaborated into larger groups of varying kinship span and corresponding genealogical depth? This is obviously a large problem which involves consideration of many aspects of the social structure but, a preliminary consideration suggests that one significant factor derives from the scale and degree of autonomy of the territorial groups or local communities. Among the Yakö of S.E. Nigeria, there is a strong tradition of compact settlement and an equally strong sentiment of village autonomy. Confining ourselves on this occasion to the patrilineal organisation of the Yakö, we find that the patriclan is a compact unit with regard to both residence and land holding. It stands as a unit as opposed to all other patriclans in the village community in the maintenance of an established share in the resources of the territory just as the village asserts its autonomy with respect to other villages. But the patriclan as a whole numbering 100 or more adult males commonly reaches a size considerably too great for the co-operative organisation of labour and for the maintenance of intimate quasi-domestic relations between its members. Genealogical and other data reveal that the patriclans have undergone continuous and complex internal processes of fission and accretion as well as expanding with increases in the number of descendants in successive generations. So that, although territorially, juridically and ritually the patriclan is a close-knit corporation under the leadership of its head, it subdivides in the sphere of transmission of particular individual rights and in the field of economic co-operation into a series of lineages which have been derived both from fission between more remote groups of patrikin with the expansion of the group, and from the accretion of outsiders whose descendants have acquired status of clan members by continued residence and informal adoption (17).

With compact settlement in autonomous communities, there is restriction on the increase in the size of the clans and of the number of its component basic lineages. When crises of internal dissension or pressure of population becomes too great for the continued territorial unity of a clan, the structure provides only the opportunity for a complete break. Among the Yakö a dissident fraction, be it a newly dividing segment of a lineage or one or more already established lineages, removes to another settlement area and abrogates its former ties of patrilineal kinship. The clans and lineages of the Hopi bear a similar structural relation both among themselves and to the autonomous pueblos or compact villages of which they form part. Fission with continued inter-segmentary relationship is possible within clan and lineage inside the pueblo, but the continuance of wider group solidarity between segments separated by migration to other pueblos, which conflicts with the economic, ritual and political autonomy of the village unit, is inhibited.

Among the Nuer, the Tallensi and the Ibo, on the other hand, the pattern of settlement does not yield such sharp territorial segregation. In the case of the Nuer, it changes seasonally with the migration from wet-season villages to dry-season camps in which the men of a minor lineage or even of an individual household may move according to their particular needs and inclinations, so that people of one village commonly scatter to several dry-season camps to stay among new neighbours. Furthermore, the wet-season settlement pattern grading through ever more inclusive groups from homestead, through hamlet and village to district and tribal section, does not involve any sharp cleavage within which a more or less closed organisation, whether for economic, ritual or, still more important, political purposes, would tend to crystallise. The most persistent factor in Nuer settlement appears to be the tendency for close patrilineal male

kin to remain together, a tendency which as Evans-Pritchard has shown, is buttressed by dominance of sentiments concerning the use and transfer of cattle in Nuer cultural values.

It appears, however, that the various tribes differ significantly in the scale of their clan organisation and in the political relations based thereon, in close relation to the extent to which the physical conditions enforce frequent and large-scale dispersal. In the better-watered western areas, where it is possible for village communities to maintain considerable isolation in the dry season as well as in the wet, tribes and their component clans are small, while among the Luo and other eastern tribes the increasing scale of both kin group and political organisation, which results in much larger tribal units with a more extensive internal segmentation, is related to severe seasonal scarcity of pasturage which compels extensive movements and temporary dispersion and intermingling of households and lineages from widely separated wet-season villages. The Nuer settlement pattern crystallises round the basic lineage of close and co-resident male patrikin which appears to be the essential nucleus ; but the exigencies of seasonal migration and past opportunities for territorial expansion with numerical growth, have permitted a proliferation of growing lineages over wide areas to form large clans which in their growth and territorial expansion have segmented many times. These have, however, in response to the continued contacts resulting from seasonal mobility and co-operation in cattle tending and raiding, maintained sentiments of solidarity over a very wide span and in terms of a genealogically very remote common ancestry. At the same time isolated, stable and autonomous village communities are lacking. The economy of combined cattle rearing and grain growing in the particular physical conditions of alternating swamp and semi-desert neither requires nor induces close and persistent attachment to fixed sites, while migration has brought into territorial proximity on favourable wet-season farming sites, sub-lineages of very diverse origin, including dependent groups from conquered tribes. In consequence we have a pattern in which any village or locality is composed of an aggregate of lineages of diverse origin. The members of the lineage and clan which can sustain a tradition of earliest settlement in the locality has the prestige of moral ownership and of precedence over segments of the other clans which have come to settle in the area, and a position of leadership in the external or political relations of the village, district or tribal section. This non-correspondence between the composition of the territorial units of Nuer society and that of wider kinship groupings is clearly dependent on the continual dispersal and territorial intermingling of the latter in response to economic exigencies in a hazardous environment.

A structurally parallel proliferation and segmentation of kin groups under conditions of relatively free territorial expansion has been observed among a number of Ibo tribes, particularly those of the north and west. It is not possible to point to any ecological factors which would account for the sharp antithesis that they present when compared with their semi-Bantu neighbours to the east, but north-western Ibo tribes such as the Ikwe and Ezza are as strongly wedded to dispersed settlement in scattered hamlets as are the Yakö to concentration in compact villages. They have, moreover, in the recent past, as the wider kinship affiliations and the traditions of migration of kin groups show, expanded by the continual throwing out of new homesteads and hamlets into unoccupied forest or into the territories of less resistant neighbours. And among these Ibo, as among the Nuer, there has in consequence been a wide proliferation of expanding unilineal kin groups. The basic patrilineages of three to five generations in depth from a single ancestor is the co-residential nucleus which normally coincides with a hamlet. The wider locality within which local economic exchange, earth cult rituals and men's societies are organised, characteristically includes a series of such lineages themselves forming a single wider lineage in relation to others of the same order that are dominant in adjacent localities. These together may in turn comprise a single major lineage in which the ancestor priest of the traditionally senior sub-lineage is the ritual leader, who wields sanctions for offences against the community at large, and focuses the unity of the lineage as a whole in opposition to threat or injury from without. Here, again, the vicissitudes of territorial expansion and differential growth have led to the territorial intermingling of lineages of different origin, some of which, although having collective rights on behalf of their members to agricultural land and equal rights to unappropriated resources in the territory as a whole, are inferior in prestige and are dependent in ritual status in relation to those which claim the first occupation of the area.

It would appear, therefore, that once social cohesion and continuity is established between close unilineal kin, the system is capable of wide proliferation through collateral kinship links in the same sense, and may form the framework of a territorial and political organisation of considerable size. Some Nuer tribes are said to number over

30,000 and the Ikwe and Ezza Ibo are of the same order. The conditions for extensive proliferation of unilineal kin and the formation of large segmented clans appear to be the maintenance of social continuity over a widening series of territorial entities, a condition which requires both considerable physical mobility and facilities for continued territorial expansion. This tendency is inhibited on the other hand by strong development of exclusiveness and self-sufficiency within local settlements and by physical or human barriers to expansion. Obviously a wide variety of factors, including physical conditions, the level of technique, opportunities for exchange, pre-existing cultural values and the political pressure of external groups, are all capable of affecting the degree to which such local isolation may be established and maintained. Where any combination of factors promotes the increase of population from a small nucleus and permits a concomitant territorial expansion, with the maintenance of cohesion through sufficient interaction between the members of the derivative communities as they hive off, the establishment of a ramifying system of unilineal kinship groups is to be expected, and under favourable conditions such a system can form the basis of a political organisation of considerable scale and complexity. Two considerable and famous political confederations, the League of Iroquois and the Ashanti Federation are instances of very extensive political organisation on this basis.

But the effective organisation of unilineal kin is, on the other hand, known to be of very limited range or of minor importance in many societies of considerable scale, including those with more advanced techniques and higher degree of economic specialisation. Lowie and others have pointed out that clan organisation tends to be absent both in the simplest and the most complex forms of social structure. We have already suggested that a threshold of stability and numerical strength must be reached before this type of organisation can emerge at the lower level. What are the factors that tend to diminish it at the other end of the scale? This again is obviously a problem that cannot be briefly handled, and space prevents its adequate consideration here. But among the processes already well recognised as inhibiting or curtailing any extensive development of a segmentary system of balanced unilineal groups as the framework of political and other organised relations, is of course the establishment of centralised political authority. When through the impact of one social system upon another, or through internal technological or other forms of cultural change takes place, some fraction of the aggregate is in a position to dominate and control the organisation of the rest through any combination of physical coercion, economic control and social prestige, the opportunity for organising such authority on centralising adminstrative and military principles tends to produce a vertical organisation with specialisation of economic and political functions. Social status of both persons and groups then derives primarily from position in the resulting hierarchy and no longer on membership of a graduated series of equal and opposite groups of kin. In such situations territorial and status interests become paramount at the expense of solidarity with remote kin, so that sentiments and group organisation which embody the former tend to extinguish the coherence of widely extended unilineal groups, and to relegate kinship ties to secondary principles of affiliation within the class and territorial structure. The Bemba, among whom the large dispersed clans display little or no sense of solidarity and the basic matrilineage is alone a coherent and self-conscious group, appear to illustrate a comparatively early stage in the atrophy of a wider system of unilineal grouping with the establishment of political centralisation.

Baldly stated in this manner, this hypothesis of the effects of political centralisation and economic specialisation on the rôle of unilineal kinship in social organisation is subject to many qualifications, but it appears consistent with the broad contrasts in the social recognition and structural importance accorded to these ties that are to be found between unilineally segmented societies and those in which a centralised system of government has been established. Some of the fundamental differences in political structure between segmentary and centralised societies have been analysed with great penetration by Fortes and Evans-Pritchard (18), who have also considered the demographic and cultural concomitants of the two types. But these raise further problems which cannot be pursued further on this occasion. I have sought only to illustrate in this brief and necessarily incomplete consideration of the processes and factors involved in the development of unilineal kin groups, the scientific value of ethnographic data secured by thorough field investigation and the importance of analytical and comparative methods in attempting to reach understanding in scientific terms of any problems of social structure and process. These are tasks and methods which have been emphasised and cultivated in Anthropology and are essential features of its approach to the development of Social Science.

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SECTION I.—PHYSIOLOGY

PHYSIOLOGY AND THE COMMUNITY

ADDRESS BY

PROF. WINIFRED CULLIS, C.B.E.,

PRESIDENT OF THE SECTION

THOUGH I deeply appreciate the great honour your Committee has done me in electing me to the office of President of the Physiology Section, I feel it is only fair that I should say to you what I said to your Committee when they overcame my reluctance to accept this office. During the greater part of the war years I have been travelling for the Ministry of Information or the Education Services of H.M. Forces and so have had little or no opportunity of knowing of recent advances in our subject.

To make up for the deficiencies of the President, the Committee, with the splendid help of the successful and long suffering Recorder, Professor Garry, who has taken on his shoulders the main burden of the arrangements and whom I can hardly adequately thank, have arranged a programme of which I hope you will approve. In it some of the more strictly scientific aspects of our subject are being reported on by those who are themselves enlarging its field of knowledge, and from whose researches the community will finally reap the benefit. We have been fortunate in securing the co-operation of fellow workers in Anthropology, Chemistry, Education and Psychology. Some of you will have already shared in the discussion on ' Penicillin and Antibiotics.' This morning we are fortunate in having papers from some of those working in the field of aviation, which is becoming more and more a matter of practical interest to the general public. It is a field, too, in which, thanks to the skill of our engineers and designers, this country is most emphatically not lagging behind. Still to come are discussions on ' Isotopes ' and on ' Climate and Health.'

Having secured the co-operation of these experts, I hope you will generously accept the limitations imposed upon your president by her war-time experiences and allow her to speak of an aspect of physiology which has always seemed to her one that deserves wider consideration than it has normally received —The Relation of Physiology to the Community—and to illustrate certain points by drawing upon personal experience in that field. This is in effect, as you will see, a plea for a wider teaching of physiology and the training of more physiologists.

Physiology as taught in our Medical Schools is the basis of Medicine, and to this audience it is unnecessary to list the very wide benefits that have come to clinical medicine from physiological studies. But it appears to me that, taught from another angle, it could be an important factor in establishing a higher standard of health and well-being in this country. If I am, as some have felt, rather a fanatic in this matter of allowing others to share in our good fortune in being students of the healthy body (and this *is* good fortune), it is because I believe its proper teaching can help in the betterment not only of our physical but also of our moral standards. If any science or subject can teach more forcibly the need of a community for co-operation between its constituent elements I don't know it.

The medical profession, as I well know from a very long and happy period in the service of my own Medical School, has done and is doing much in this field of health education. Their work as Medical Officers of Health, as School Medical Officers, in Maternity and Child Welfare Centres and in many other organisations is of the greatest value. But the work of these experts would have greater effect still if it could be based on an understanding by the community of the principles of healthy living derived from a sound knowledge of the functioning of the healthy body.

This information must of course be given on the lines of functioning of the *healthy* body so that it does not lead to the appearance of a crop of amateur doctors ! The great interest shown by the general public in advances of medical knowledge, fostered by pseudo-medical articles in the popular press, shows the need for some such education. It should also engender a more intelligent

attitude towards some of the more extravagant claims of various preparations offered to the public and described in such attractive verbiage. Proper teaching would also help towards a realisation of the gap that normally has to be bridged between the making of the first fundamental discovery and the full knowledge necessary for its practical use. Penicillin, sulfa drugs, streptomycin are becoming familiar, almost household names with little realisation that much has still to be learned to ensure their completely wise and safe use.

As far back as the end of 1944 in a small town in British Columbia, quite close to the Alaskan border, a medical practitioner told me of a disgruntled and highly disgusted patient who was leaving one doctor after another because he was refused treatment with penicillin for a quite ordinary sore throat, at a time when supplies of the material were very precious and hard to come by.

The 'insulin' story has many points of general educational value and is a good example of the gap between intelligent anticipation and realisation. As you all know the experimental work of von Mering and Minkowski in 1889 definitely established the relationship between failure of pancreatic function and disorders of carbohydrate metabolism. Yet 30 years, during which research was carried on in many countries, elapsed before Banting and Best in 1922 were able to obtain the active principle. Even then investigation and co-operation in many fields were necessary before the happy result was obtained which has changed the cramped and precarious life of the diabetic to the full and vigorous one that may be his to-day. Most of us, I expect, know of lives that have been transformed in this way, but an outstanding example of what that may mean not only to the sufferer himself but also to others is the case of Minot, a man whose life was saved by insulin and the man to whom primarily we owe the removal of pernicious anæmia from the list of fatal diseases. It is interesting to note that his liver treatment was suggested by investigation of what might be regarded as a very academic problem, the materials leading to an increase in the output of bile pigments.

There are other points of interest in this story. You may remember that to protect the public against the obvious dangers of exploitation of Banting and Best's discovery the preparation of 'Insulin' was patented, though at the time there was considerable outcry against this procedure. The patent rights were given to the University of Toronto and not used for the financial benefit of its discoverers. In this country the rights were given to the Medical Research Council. I vividly remember a talk with Sir Walter Fletcher, its then Secretary, about this. The general public hardly realised that, since insulin treatment had to be continuous, each new diabetic patient meant an increased demand on the small amount of material available. Selection of the few cases to be saved imposed a terrible responsibility. The M.R.C. decided, therefore, that its first duty was to increase the supply, by improving the technique of obtaining it. Only after considerable supplies were available was treatment given, and then to patients in those hospitals that were equipped to follow the blood sugar level. Another point he made, which was very satisfactory, was the attitude adopted by the men of the Smithfield Market. Pancreatic supplies with this new life-saving potentiality had a value which might well have been used to make the public pay a much enhanced price for it. When the position was explained there was at once a decision not to raise the price above that of the days of its sweetbread value. This surely is an example of good results accruing from increased and shared knowledge.

War and the necessary restrictions of wartime conditions have awakened a keen and practical interest in another aspect of our science, right feeding. This is a matter whose importance can hardly be overrated. Correct and good feeding is rightly regarded as the greatest single factor in the maintenance of health, though to-day some may feel it is very closely followed by that of correct and good housing where also physiology has much to contribute.

In good feeding the community, largely unknowingly, owes a great debt to physiology. May I at this point pay my tribute of respect and affection to that very great man of our science, Sir Frederick Gowland Hopkins, to whose contribution in this field we all owe so much. In the last century with its important recognition of the energy values of foodstuffs, food was mainly studied in relation to its calorie value or, in other words, in its quantitative aspect. It was generally assumed that, if the diet contained sufficient calories to provide for heat and work and sufficient protein to replace the loss in wear and tear of that one class of foodstuff the body could not build, the food needs of the body would be met.

It is largely due to the work of Professor Hopkins that the need of evaluation in terms of quality as well as quantity were realised. His experiments showing the necessity for certain amino acids such as tryptophane and lysin for maintenance and growth opened up new conceptions expressed in such terms as 'biological value' or 'high grade proteins.' Again a personal recollection. Sir Frederick

once told me how at a public lecture he laboured, as he feared unavailingly, to explain the reason for the value of animal protein in our dietary. The next morning he was horrified to find how successful he had been when a headline said 'Eminent Scientist says the proper food of Man is Man.' His work on the 'Accessory Food Factors' or vitamins as they are now called and the benefits arising from it are so well known that it is unnecessary to do more than mention it. But there is an aspect of his work not so widely recognised. In the war of 1914-18, it was only a strenuous fight on the part of Professor Hopkins and his fellow members of the food advisory committee, coupled with the appointment of Lord Rhondda as Minister of Food, that prevented the elimination of fat from our dietary. In Germany, where the view was accepted that an adequate dietary was a matter of calories, fat was replaced by carbohydrates of equivalent calorie value, with the consequent lowering of the standard of physical health.

The need for the rationing of essential foodstuffs when these are in short supply is recognised by all. The help given to those in the lower income bracket by the heavy food subsidies at present in force and special allocations of milk and vitamins to children and expectant mothers is also realised. But, with a basic diet providing only 1,500 Calories a day which, even with the points materials added, does not much exceed 2,000 Calories, there are many cases that call for consideration. There is however, one group for which there is a strong, almost urgent, need for reconsideration, the case of those persons, often elderly, living alone on very slender incomes. It is only necessary to look at the week's rations for such persons to realise their great need. A short time ago I had a letter of impassioned appeal from a retired physiologist living in the country giving chapter and verse for the need for help for such persons. In the villages there are no British Restaurants, no places for getting extra meals. Many of the points materials are so expensive they cannot be bought. Gardens are often lacking or when existent their occupants are too old to make use of them. In towns the same group finds life equally difficult, fruit and vegetables being often at a prohibitive price. I myself know of cases where such persons who cannot stand in queues would have been almost at starvation level but for gifts of food from others and from friends abroad. Households with large numbers are in contrast almost over supplied. Is it not time that something should be done to provide for persons in this unfortunate position? The situation is largely due to lack of understanding. Compare the outpouring of sympathy to the old age pensioner threatened with curtailment of tobacco supplies with the acceptance of almost tragic conditions of many of them as regards necessary foods. This surely is a case where a little more knowledge would lead to a needed reform. Nutrition is a matter of such paramount importance that it is easy to see how necessary it is to have instruction as to what constitutes correct and adequate feeding. This brings me to my plea for more teachers.

To spread the knowledge of what physiology has done and can do in the promotion of the well being of the community, it is vitally necessary to have more well qualified teachers. For this purpose I hope that in the Universities more and more students will read physiology with its ancillary sciences following the lines laid down at Cambridge many years ago by Sir Michael Foster, a very great teacher of physiology. He wanted students to read it who were not necessarily going on to medicine. When there is an adequate supply of these, they will be available for the ordinary Training Colleges and in the Physical and Domestic Science Training Colleges whose authorities to-day advertise in vain for such teachers, and in the Schools themselves where in the middle and upper classes they can build upon a foundation laid down amongst the younger pupils by good courses in general biology. And here, from a wide experience as examiner in hygiene in the Training Colleges, I should like to say how much the teaching of biology and of underlying physiological principles has improved in recent years. In Colleges fortunate enough to have on their staffs good biology teachers, the work of the students reaches a very high level, which is passed on to their pupils in the schools. In many schools in poorer districts the teachers of biology and of physical training are having a marked effect on carriage and cleanliness, two important factors in health and self respect.

In many schools to-day the teachers have available the aids given by films and by broadcasting, and here may I stress that these two new media of instruction are only *aids*. They in no way lessen the responsibility of the class teacher, rather they can be said to increase it. They are new techniques, in the proper use of which the teachers must themselves be instructed. If this cannot be secured in the Colleges, then the Local Education Authorities should see to it that such instruction is made available for those teachers who wish to avail themselves of these aids. Speaking from my own experience, as I am so largely doing in this talk, I should like to say how much help has been provided

in the various vacation and other schools organised for teachers by the British Film Institute for films and by the B.B.C. for broadcasts. But there are not enough of these to satisfy the numbers of teachers who unavailingly ask to attend such courses.

As regards schools broadcasting I should like to offer my meed of appreciation of the work of Miss Mary Somerville, who was the originator of what has become a well recognised and valuable service. At her invitation and with the consent of the Council of the Medical School, who were somewhat startled at a University Professor being asked to inaugurate such a course, the experiment was tried of giving broadcast teaching in physiology and hygiene. There had been much doubt as to its suitability, but it became a regular feature and I must say that I enjoyed working out the course, which after three years was shared with Professor Mackinnon, whose subject was botany, for a further two years. All the time I was doing this series it was possible to sense an anxiety on the part of the B.B.C. authorities that in some way we might attempt to give instruction in sex physiology, which we had no intention of doing at that stage. This made it all the more interesting to me when, on one of my returns to England asking how the biology course was going, I was told that it now included not only reproduction in plants, but also in animals and finally in man.

One thing that surprised me very much in broadcasting which, before I had done a continued series of talks, had always seemed to me to be so impersonal, was the queerly close contact that somehow develops between the two sides of the microphone. One's audience takes on a personality, helped of course by many letters that come to one and the curious experience of meeting people in quite remote parts who have met one on ' the air,' so that one loses the sense of talking to a microphone and feels that one is talking to a very friendly audience. The response to a single talk can be almost alarming. I remember once, a long time ago before programmes were so closely organised, being asked to allow a talk on ductless glands I was giving to an audience interested in general science to be broadcast. It was nearly an hour's lecture and letters asking for help came in hundreds, more than 400 with stamped addressed envelopes, making me realise how desperately ignorant people were as to where to go for help, a situation which I hope has largely improved with the wider availability of medical help, and the knowledge that help can be given.

Besides having had experience in broadcast teaching, I have been lucky enough to have had a small experience in the making of teaching films. This came from the suggestion by some of the teachers taking the broadcast lessons that it might be useful to have some films to be used with these lessons. Gaumont British Instructional asked me to undertake the preparation of some simple physiological films as an experiment. It was an experiment and an experience, and one that was only made possible by the help given by the expert film makers to those of us with some knowledge of physiology but none of film making. I wish particularly to stress the way in which these experts co-operated. Never once did they refuse to retake or modify, sometimes at considerable cost, any part of the film which did not seem to us to be correct. The films were made in the laboratories of The Royal Free Hospital School with the co-operation of my staff, and it was an interesting and at times a most disconcerting experience ! To-day, in view of the great improvements in technique which film production shows, these films would probably appear crude, but there is one merit we can claim for them ; every experiment shown is a genuine one, faithfully recorded with no faking. I have been asked to kelp in the remaking of the film on ' Circulation,' this time in technicolour. It was hoped this would have been ready to show you, but it has been held up by various unforeseen circumstances.

In both these fields experience has shown that the best results will be obtained by collaboration between the classroom teacher and the experts both in subject and medium. Educational films have been so much used in training in the Services that their value as a teaching medium is well established. War-time conditions, may we hope, have broken down the vicious circle which hitherto has handicapped their use. Absence of projectors has meant little use of the films available, and this small demand has reacted on the number of films produced. It is hoped that many of the projectors if they are in good order will be passed on to the schools.

In broadcasting it was very clearly shown me that how much the children got from these lessons depended very largely on the co-operation of the classroom teacher.

Another way in which properly qualified physiologists could give valuable service would be in the collection of reliable personal physiological data, particularly in the Training Colleges where the collection of such data would be part of the training of the students. This has been done for many years in our laboratories at the Medical School where, under proper supervision, it has formed part of the students' practical work. Observations of this kind will be of special value under the present rationing conditions, more

particularly in residential Colleges where all meals are taken in the Colleges. From the colleges of Physical Training, data so obtained would show whether the authorities of these colleges were justified or not in their requests to the Ministry of Food for some increase in the rations of those who, of necessity, are doing hard physical work in their training.

There are many fields in which needed and desired teaching is held up by scarcity of trained physiologists; social service courses in the Universities, organisations specialising in various forms of physical training, W.E.A. classes, and collected groups where such teaching would be of use and much appreciated by the members.

Physiology is a good subject. It is not only fascinating in itself but to its exponents it gives great scope for service in the field of general education as well as in medicine. Is it because it is such a humanising subject that I have found my fellow physiologists such very pleasant and understanding colleagues?

At any rate I am sure that if my wish for many more of them in the world of general education should come true, they will be a great asset to any group fortunate enough to have their services.

SECTION J.—PSYCHOLOGY

MAN'S ADAPTABILITY

ADDRESS BY

DR. S. J. F. PHILPOTT, M.C.

PRESIDENT OF THE SECTION

1. The Problem

When plans for this conference were drawn up it was suggested that presidential addresses should deal with the general problem of swords into ploughshares and that the treatment should be non-technical. As it happened, I had already been thinking towards a kindred problem, that of turning John Jones, bank clerk, into John Jones, tank gunner. Just how or why can it happen? If he was a round peg in a round hole in the bank, just what kind of a peg would he be in the Army?

As so expressed, the problem involves the change from peace to war. It misses some of the symbolism of the sword-ploughshare conception. On the other hand, one of the fundamental psychological problems involved is that of adaptability. The metal of which the sword is made must be adaptable. The smith making the change must be capable of making adaptations. If therefore we deal with the problem of adaptability in general, we shall be touching on one vital aspect of the sword-ploughshare problem even if we depart from it in some respects.

Human agency is essential. It needs a smith to make the change. Man is above all things an artificer. Sometimes his work is repetitive. Sometimes he is hammering out a fresh design. But in any case he is creative. Even in the small things of life we recognise the creative tendency as when we say of a man that he is capable of building a car out of a pile of junk, or when we say of a woman that she can conjure Parisian creations out of the family rag-bag.

The sword-ploughshare transition implies the change from weapon to tool. It will not be necessary here to stress that aspect of things. Nor shall I dwell on the fact that it deals with the transition from destruction to construction. To me, that would import an element of unreality. Nature gives the animal teeth and claws that are used indiscriminately whether as tools or weapons. In fact, looking at Nature, red of tooth and claw, it is the weapon aspect of things that is the more obvious. I shall therefore speak of weapons as tools, ignoring the fact that they are used for killing. As far as that goes, even a plough is lethal. It turns up the weeds; it unearths slugs and other small creatures for destruction. It is a pathetic as well as a dangerous delusion to think that wars can cease. With lethal weapons as between nations they *will* perhaps cease. I have faith that way. But war in the sense of conflict is a fundamental of existence.

In thus dwelling for a moment on the problem of conflict, my trend of thought was rather towards peace and war as such. Our task is rather to deal with the problem of adapting man whether to peace or war. A line of thought leading in the right direction is indicated when we note that people sometimes speak of born shots or born tacticians, while in the same breath proudly boasting that every private soldier carries a marshal's baton in his pack. These notions cannot both be literally true. If some are born to be shots or tacticians, others are born to be marshals. If that is the case, it is foolish and wrong to tell the people that they all have the same chance of promotion. Or again, if men were born to be car drivers, it would be legitimate to inquire what happened to the born drivers of the days before cars were invented, or what is happening to-day to the men who would have been charioteers competing in the arenas of Rome had they been born earlier.

It is an obvious fact that men of any given age will be employed on tasks characteristic of that age. In this respect, man differs from the animals. The robber crab was literally born to climb coconut palms. The wasp Sphex was born to behave in the fashion that has made her species famous. Man is more adaptable. He turns his hand to many things. Born in this present age, he may be functioning as a tank driver. Born under one of the Caesars, he might have been a gladiator.

Many practical problems arise when we come to the twin problems of vocational

guidance and selection. How did our ancestors distinguish (if at all) between those born to be charioteers and those born to be swordsmen? In our own age, how can we distinguish between born tank drivers and born tank gunners? In the school world, how are we to distinguish between children who need to go to Grammar Schools and those whose needs would take them to Technical or Commercial or Modern Secondary Schools?

Guidance has to do with the individual. John Jones, bank clerk, had many hopes and fears when, caught up in the army machine, he reported for test and interview. He wanted to be posted to the most appropriate regiment with the highest possible rank and the most suitable job. He looked for advice and guidance. Could someone tell him how to get what he wanted? What *ought* he to want anyway? Taking each man in turn, those responsible for testing and interviewing were able to give some little time to the study of these individual needs, two or three ' training recommendations ' then being entered on each man's form.

Processes of selection are rather different. Those responsible for it in the Army have to ensure that a stream of good material is directed into each unit. No system is perfect, and misfits are inevitable. Those responsible have to ensure that the wastage rate is kept as low as possible, checking and cross checking on methods until that end is attained. If John Jones, one time bank clerk, ultimately finds that he has become a misfit in the Army after all, he will be annoyed. He will proclaim aloud that the system is bad. On the other hand, as long as the percentage of misfits has been kept at a minimum, the selection staff will be held to have worked efficiently. That John Jones may have suffered is a pity, but it cannot be helped.

By guidance then, we do our best for the individual. By selection, we do our best for the Army, or the industry, or the education authority concerned. The problem of testing has been mentioned. Is it possible, for example, to devise tests that shall pick out potential cooks as distinct from potential clerks? Can we distinguish between potential tank gunners and tank drivers? There are so many misunderstandings in this matter of tests that we had better indicate some of the main problems involved.

When it was first suggested to set up a Directorate of Selection of Personnel in the Army, some of us were asked to tour the various Commands to see what had already been attempted, for some units were already using tests in tentative fashion. I remember going into a Tank Training Regiment where a rather puzzled young officer was in charge of two pieces of apparatus. Brass instruments in psychology are always rather awe-inspiring —except perhaps to Tommy Atkins who coined the name ' fruit-machines ' for them. Examining the two bits of apparatus in question, I realised what was in the mind of the psychologist who had lent them to the unit. He was using two slightly different tests of hand and eye to see if drivers and gunners behave differently with them. It was worth trying, although I do not think anything ultimately came of it. The young officer in charge did not realise the tentative nature of the whole affair. He took it very seriously. One instrument being called the driver machine and the other the gunner machine, he was perhaps to be forgiven for taking those names on the labels at face value. Nevertheless, even he himself had come to feel there was something wrong. For as I turned away, he diffidently asked if I thought the labels could have been changed over in transit. In his judgment, the driver machine was picking gunners and *vice versa*.

The right answer was that in all probability *each* instrument was doing *both* tasks and doing them equally badly. They were both tests of co-ordination of hand and eye, and to that extent both would pick out people likely to excel in *any* operation calling for that co-ordination.

Stories of the kind could be multiplied indefinitely. They depend for their rather subtle humour on the fact that the victims have been naively convinced of the value of the labels. We all tend to fall into that trap. Having given a dog a bad name we hang him. Having heard that a given test was designed with the selection of potential clerks in mind, we are surprised if, later, it is used to pick out potential cooks, or signallers, and so on.

Many of the qualities required in any one occupation are also required in others. It follows at once that it would be very difficult to devise tests uniquely characteristic of just one occupation. If two given occupations have 50 per cent. of their factors in common, perfect tests for those occupations will themselves have 50 per cent. in common. Overlap in the jobs means overlap in the tests. So that going back to the illustration bank clerk into tank gunner, if we accept that change as possible, it is illogical to manifest surprise when tests for bank clerks prove to be suitable for use with gunners.

People sometimes run to extremes in their judgments at this point. If tests are many sided, what use are they in selection? Are we not in danger of sending potential clerks to function as cooks? Most obviously we are, but that is happening in all spheres of

life. The whole point about any given man is that in his time he can play many parts. Why then argue that he is a Shylock wasted when he is playing Hamlet, and *vice versa*?

At this point I am going to be met with the argument that for each of us there is a part in which we excel and that we ought therefore to specialise in it. I admit the force of the argument. What I am trying to urge is that the popular interpretation of tests tends to ignore man's versatility somewhat, while at the same time over emphasising (if anything) the extent or measure of variability as between the various parts he may be playing. It would be a tragedy if misinterpretation of test results in this sense were to lead to a limiting of man's choice when seeking a job. Let me therefore argue at once that, rightly understood and appreciated, the standard tests of to-day are tests of versatility rather than of specific aptitudes.

Going off at another tangent, critics might here urge that *if* we are all so adaptable, if we can all be cooks, or clerks or bottle-washers, we can (by the same argument) be commanders-in-chief and prime ministers.

The fallacy here is that we have been speaking of potentialities. We are most of us potential cooks or potential clerks, and so on. But before we can step into a job, we must be trained, and training may take half a lifetime. The matter of training is a big enough problem, in itself, to prevent most people ever attaining high office in the State. But there is another element in the complex of importance as great or even greater. We have so far stressed man's versatility. But it is always manifested on what may be called the same 'horizontal level.' If I pass from one occupation to another, the question always arises whether I am stepping up or stepping down, and although the man in the street may not be able to put the notion into words, it is always implicit in popular speech that the step up or the step down is in respect of all-round ability—save, of course, when the problem of social level comes in to obscure the issue.

These points may seem too obvious to be made, but it is perhaps as well to get them into the picture. If we are to speak of adaptability, we must indicate the limits. I am speaking of it as occurring only within the intelligence level of the person concerned.

Crystallising some of the things already said, the position can be summed up in terms of two extreme cases.

We *might* have been born each with just one special gift, being born carpenters, born chemists, or what not. Alternatively, we might have been born merely with all-round ability, potentially anything, but specifically nothing in particular.

If Nature had worked in the first way, ordaining that given men fill given niches, she would probably have given them distinguishing marks, whether physical or mental. The robber crab has its modified claw with which to get at the inside of the coconut. The man born to open bottles might well have had a finger modified as a corkscrew. The born clerk might have had a pen finger. There are no such distinguishing marks, although a glance at the equipment of some of the lower animals will show what Nature could have done had she so willed. On the mental side, the story is the same. The equipment of the potential clerk is not distinguishable from that of the potential cook. So that although ultimately they may *acquire* differences, obvious enough to be apparent to a Sherlock Holmes, or to be described and assessed in a more formal examination, they are not inborn. Nature did not worry about the characteristics of the ideal woman cook. It was sufficient to create an efficient woman.

With this, we have arrived at the other extreme view, namely that we are born potential jacks of all trades, with minds and bodies fitted for general purposes use. If so, the critical problem of testing is to get at that general purposes ability, asking not which specific thing John Jones was born to be, but what he is generally, whether he is a man who makes a success of everything he touches, or whether he would muddle anything. Given a judgment in these terms, we can hazard a guess as to whether he, at the moment bank clerk, would be likely to make good at gunnery.

Still looking at these matters from various angles to get them in perspective, we may raise the question of planning or devising tests. Given the task of finding tests for job X, just how ought one to proceed? To some extent, we are here going back on our tracks, for the essential notion has already been given. But forgetting that for a moment, let the problem be looked at afresh, again from two extreme angles. We can work either by way of a study of the job and of suggested test situations or we can forget the job altogether, undertaking a study of the kind of people who can already do the said job whether well, moderately or badly. Just what kind of people are they?

Making the first approach, let it be supposed that we have arrived at an analysis of the job. In our view, it calls for mental qualities A, B and C. The next step would be to suggest tests for those three qualities. That done, it might seem that all we have left to do is to apply those tests to candidates for employment, choosing those best qualified therein. That this method of approach may

lead to trouble is obvious. Too much depends on the judgment of the investigator. He has to make an analysis of the job; he has to analyse the test situations suggested. He has then to decide, in cold blood, just how far those analyses run in parallel. I say 'in cold blood' for the temptation is to fall in love with one's tests. They can seem so completely satisfactory. The job analysis and the test analysis may seem so perfectly in parallel. One may be tempted to put the tests right into use without further delay. And it must be admitted that tests *have* gone into use with little else to justify them than this criterion of the paired job analysis.

Much outside criticism goes wrong because the same criterion is being used by onlookers. Again and again, one hears the criticism that so-called intelligence tests cannot be testing it because the questions do not look intelligent. The critics have here analysed the job of 'behaving intelligently'; they have next analysed the job of 'answering test questions'; they have come to the conclusion that the two analyses do not run in parallel. And once people have reacted in such fashion, it is not easy to convince them. It was to meet such situations—as much as in a desire to adopt a more exact approach—that Spearman erected two practical defences. He began the custom of calling the factor of all-round ability 'g' instead of using the more usual word 'intelligence' while, further, he stressed what he called the canon of 'Indifference of the Indicator,' saying that as long as a test does what it is wanted to do, we may not criticise it because it does not fit in with our preconceived notions.

The other extreme method of approach is by study of a typical group of workers. We want a test of job X. Gathering a representative group of people of known ability in the job—good, middling and bad—we ask just what kind of people they are. We know their order of merit at the job. Is it the same as their order for stature? Is it the same as their order of merit in arithmetic? Asking many such questions, we may ultimately find a test that gives the desired order of merit. If so, we shall have found what we want. And once more, the canon of Indifference of the Indicator may help if *a priori* criticism is aroused.

In practice, we do not usually go to either extreme. Broadly speaking, we tend to approach the method of paired job analyses when trying to devise a test for some quite specific performance. The 'fruit machines' supposed to help in the choosing of drivers and gunners are cases in point. Analysing the job of gunnery on the one hand and the job of working the given test on the other, and, asking whether the two analyses go in parallel, we may be quite convinced that there is a *prima facie* case. We tend to go to the other extreme, that of paired class lists, when working on large-scale tests of a more general kind.

In the Army it was required, almost at a moment's notice, to devise a system within which those working under the Directorate of Selection of Personnel could handle (*a*) millions of men generally, and (*b*) smaller numbers of potential workers at certain highly skilled jobs.

The broad general scheme for men in their millions is the problem that interests us here. The first requirement was a test of all-round ability. There are many such tests. The Army used several, the best known being the Matrix Test given to all recruits on joining. From this, the man's general level was determined. Depending on his results in that test, and on his civilian record, other tests were applied, tests of simple arithmetic, of simple science, of mechanical ability. For potential signallers there were tests of hearing and Morse aptitude.

There is no time to discuss the problems that arise at every point in such work. One general notion may, however, be elaborated slightly. It is that of cut-off limits. It is not economical to employ a man at a job for which he has not the necessary intelligence. He will never understand what he is doing. It is therefore necessary to go into the statistics of the matter, asking just where the line should be drawn to give the smallest possible number of misfits in the circumstances. For some things, an upper limit must be drawn as well. It is no use sending highly intelligent men to be hewers of wood and drawers of water. Wherefore, it may be necessary to draw an upper level above which no man will be accepted.

Working out a lower limit, and sometimes an upper limit, for this task or that in the Army, whether for intelligence, mechanical ability, hearing, ability to do arithmetic, and so on, it was made possible to supply Personnel Selection Officers with a broad scheme within which to work. Given a man's scores for the various tests they can tell at once whether he is too good for this task or not good enough for that.

Such tables of cut-off scores are, of course, for the *guidance* of the Personnel Selection Officers. They have to be applied with care. Applied woodenly they might even stultify the whole system. Thus, for example, were we to devise a test for every conceivable quality required for a given job, and were we to work out accurately the limiting score for each, the net result might be that we should reject everyone without exception,

turning down one man because he is too tall, another because he is too short, and so on.

That this method of selection must break down if carried too far is obvious. In everyday life goodness in one respect often compensates for defect or deficiency in other directions. Some succeed at sport because of superabounding energy ; others because they have reduced economy of effort to a fine art. There are many roads to efficiency. The system of selection under discussion depends on the implicit assumption that a man who fails by one road must fail by all—a clearly untenable notion.[1]

In practice then, the essential measure is of all-round ability. Given that, we must usually have a few cut-off requirements. Some occupations require that a man shall have two legs. For others an artificial leg would not necessarily disqualify.

We get the same kind of thing in the educational world. Entry to a Grammar School obviously depends on all-round ability. Unless the child is intelligent enough, he will not make the grade. But there are a few cut-off requirements as well. No matter how intelligent he is, he will not be a suitable candidate unless he can read and write. He must have those two techniques if he is to gain anything at all from the Grammar School curriculum. He must also be able to do simple arithmetic. But beyond a few very necessary requirements of the kind, the fewer tests the better—once those of all-round ability are given and passed.

It is necessary to inquire just what broad tendencies we are hoping to measure or assess in a scheme such as that briefly outlined a moment ago to illustrate what was done in the Army. As we have said, there is the *general* factor of all-round ability. Next, we try to account for certain *group* factors, so called because they run through groups of performances. There is ' v ' the factor that runs through tests involving the use and understanding of verbal material. The group factor ' n ' runs through performances involving the use of figures or calculations. Group factor ' k ' appears in tests involving the comparison and use of spatial diagrams, group factor ' m ' similarly appearing in tests of mechanical ability. Over and above there is a factor symbolised as ' ed ' that depends on educational background.

By somewhat elaborate calculations it is possible to analyse given performances, saying that this one calls for so much ' g,' so much ' v ' and so much ' ed ' ; saying that this other performance depends on ' g,' ' k ' and ' m ' again in given proportions, and so on.

Specific factors also enter. We have not said much about them under that name. By definition, they are peculiar to a given task. In the main, they are probably rooted in acquired techniques, in the thousand and one little tricks and rituals of life that we forget until we study ' wolf children ' and come to realise how much such little outcasts have lost. Over and above this literally enormous equipment in terms of acquired drills, there are the given individual's likes and dislikes, his temperament, his sensory equipment, peculiarities in anatomical build, and so on. We need not discuss these factors at length because the major problems of adaptability probably depend on the broader group and general factors concerned. But one must not ignore the specific side. A person cannot adapt if he is weak in the specifics demanded by a given occupation. It is difficult, for example, for a person affected by a stutter to adapt himself to the art of teaching a class. His all-round ability may be good enough, but it will not carry him all the way if he cannot talk easily and freely.

II. Problems of Equipment

Having just closed the last section with problems of adapting to new situations when the specific organ is faulty, we ought perhaps to turn more explicitly to a few problems of equipment. Just what can we say man has with which to implement his various activities ? What are the general purposes tools with which he tackles so many different problems ?

Matters of physical equipment are relatively simple to understand. We can see our hands ; we can count our fingers. Problems of mental equipment are more difficult. It is not possible to make mental things evident to the senses. In consequence, man has always tended to invent hypothetical mental organs, faculties, abilities, powers, call them what you will, and it is here we run into trouble. We pay lip-service to the doctrine that the old faculty psychology is dead while yet speaking quite freely about abilities and powers. It is not consistent to

[1] There are two fundamental methods of dealing with results from a large number of different tests. We can add all the marks together to get a measure of ' all-round ability.' This is because those who are able to turn their hands to (almost) anything will tend to get high marks all round and *vice versa*. Any given man's total mark will be a measure of that general tendency. Moreover, the more varied the tests, the more likely we are to get a true all-round measure.

The other method of handling the scores is the ' cut-off ' system described in the text. The search is here for the specific tests in which a given individual is (*a*) weakest or (*b*) strongest. Even a good all-round person will sooner or later find himself failing in respect of some one or more specific tests ; even a mental defective can sometimes excel in a specific skill.

condemn theorising that looks upon memorising as a matter depending on the faculty of memory if we speak of arithmetical ability or essay writing ability, and so on, using the terms as though they stood for definite 'machines' in the mental factory.

In an attempt to get behind or beyond language of the kind, it is often convenient to speak in terms of 'attitudes' whether of body or mind. On the physical side the term means that the body as a whole is involved. I can throw myself into the attitudes appropriate to cycling, to digging, to sawing wood, and so on. In every case, it is my body as a whole that is involved. I use the same general purposes set of muscles, the same bony framework, and so on. I do not possess a special set of muscles for gardening, and another for typing.

In the higher realms of sport, attitudes are all important. No man can be a world champion unless he has a body lending itself perfectly to the peculiar movements of the sport in question. Just what the factors of success may be we do not know. Perhaps the right length of muscle here, the right strength there, the right niceness of balance somewhere else. Or again, there may be more than one combination of factors leading to success. Bradman and Jack Hobbs were alike in being outstanding cricketers, but they were not cast in the same mould.

It is not as easy to envisage the mind being used as a whole in this same sense. Yet we can well imagine it being thrown into the attitude appropriate to cricket, the attitude appropriate to golf, to higher mathematics, to a religious exercise, to a political argument. It is the same mind that I am using at this moment when getting sentences in order that I use in getting figures in order. Moreover, of course, just as there are champions of sport, so there are champions of the mental world; just as there are many kinds of first-class cricketers, so there are many types of first-class intellect.

It is dangerous to think of specific mental 'gifts.' It is much safer to think of a general purposes mind that can fill many rôles, that like an actor can live now the part of a mathematician, now the part of a carpenter, now the part of a sportsman. Looking at things from this angle, it is as well to study the more primitive peoples, asking what happens when they come to adapt themselves to higher cultures. I am not thinking of the interaction between cultures as such, but of the way in which individuals from the more primitive world come to adapt themselves. In many parts of the world, youngsters whose grandparents were naked savages, perhaps of cannibalistic tendencies, are to-day students of philosophy, of science and the arts. They are becoming medical men, teachers or skilled mechanics, each man capable of holding his own when competing with people of comparable intellectual level in our higher civilisation. That savages can become adapted to the most sophisticated civilisation within a couple of generations indicates that whatever 'mental gifts' are used by philosophers or men of science or artists in the civilised world of to-day must also have been present in the savages of yesterday. They could not have evolved in a couple of generations. As far as that goes, we can argue from our own race. The said mental gifts could not have developed in the few generations that have passed since woad went out of fashion. So that whatever Nature has given man, must have been with him from the beginning. The 'machinery' we use when doing an involved mathematical problem must also have been possessed by even the most illiterate of our distant ancestors.

In many ways the practical problem reduces to a question of the *use* we make of our mental powers—whatever they may be. As it were, Nature issues all men with a standard set of instruments or tools, telling them to get on with the job of using them. Some seem to be issued with more highly polished tools than others; they become the master men. Some have very rough tools: they become hewers of wood and drawers of water to the more highly endowed members of society. But whether polished or rough, man has to do his best with the tools he has got. The parable of the talents holds.

Given the tools, creative genius works through techniques. The child cannot hope to compete with an artist when it comes to making use of a box of paints. Every trade or profession has its secrets; every man has to learn the tricks of his particular trade. The pianist works at his trills. The carpenter learns to cut to exact measure, so making neat joints. Whence we come to a new thought. Body and mind together constitute a general purposes instrument in the sense that a cathedral organ has general purposes use in that it can be used to express almost any form of music. It has to be granted that we cannot get everything even from a large organ. But within its limitations it has general purposes functions. But with man, we get that something extra, something the organ has not got, namely the person himself working in and through his own mind-body instrument. And with him, acquired skills in the use of the instrument are as much 'equipment' as would be additional stops on the organ itself.

We speak in this sense when we say that a given child is leaving school well equipped for

life. Just what has he gained in school? Essentially, a set of techniques. First and foremost come the three R's. They are the techniques that underlie most things. Then come such things as the tricks and devices behind the arts and crafts of drawing, painting, needlework, handicrafts, and so on. With the informational subjects like history and geography it might be urged that ' facts ' are equipment, but there still come techniques, as, for example, the art of map reading, the art of looking up references in the literature.

In saying that functions of this kind are equipment, we come very near confusing structure and function. But that is a danger always present in psychology. Without wanting to bring in outside issues, we may note that if we take a long-distance view of the individual, getting a momentarily quickened picture of the whole of his life-history, we can envisage the one-celled egg beginning to function as such, and by so doing, taking on a two-celled structure. Functioning in ways appropriate to that structure it becomes four-celled, and so on. Leap-frogging through the stages of development, functioning in appropriate fashion at every stage, the embryo becomes an infant, the infant becomes a child and the child a man. Having become a man the individual functions perhaps as a farm-hand, perhaps as a city clerk. In either case, he ultimately becomes gnarled and bent, rather more so in the one occupation than in the other.

When the process has gone beyond certain limits, we realise that the change from farm-hand to clerk or *vice versa*, while still perhaps possible, would not be a practical proposition. It would be wasteful as judged by the standards of the social group. We should lose the accumulated experience of the farm-hand if he became an amateurish clerk, and conversely. In other words, we here look upon accumulated experience as equipment. Moreover, although as psychologists we accept the fact that there may be many and subtle bodily changes involved, whether in becoming a farm-hand, or in changing from farm-hand to clerk, we are not inclined to attach importance to them when discussing the transition from farm-hand to clerk. We think more of the experiences and skills, of things functional rather than things structural, although both are involved.

We can illustrate a little further by thinking for a moment of the old notion that there is a definite part of the brain to be used when (and only when) we are doing arithmetic, another to be used simply and solely when doing some one other thing, and so on. On that theory, a child who cannot do his sums might be held to lack the necessary brain cells. Nowadays, we do not attach much importance to such a picture of what happens. The first question is whether such a child is intelligent enough to do arithmetic at all. If he is not, the answer is that it may be impossible to teach him. If he *is* intelligent enough, then the chances are that the teaching he has received is at fault. He may have missed one or more of the key lessons of the course. For lacking one or more of the essential techniques even a bright child will be in difficulties.

Similarly with all problems of illiteracy. If low ' g ' is the cause, we can do nothing about it. But if the ' g ' is there, then failure to profit by teaching in the past may have been due to absence from key lessons, or lack of desire to learn, or quite a number of other factors. In such cases, remedial teaching can be undertaken. This extension of educational work is growing in importance. More people are required for it than are available. Incidentally, the Army Education authorities devoted a good deal of attention to the problem during the later years of the war. A soldier who cannot manage one or more of the three R's is a liability in these days of universal education. But obviously, any attempt to educate him must depend on his desire to learn and, above all, on his having enough ' g ' to attempt the task.

The picture then is of a man with a general purposes body and mind, using that body-mind instrument as a whole, playing on it in the execution of the rather complex operations of everyday life. Such a picture differs quite widely from that we get when studying some of the lower animals. It is true that their equipment has general purposes value in some respects. But we tend to think of them as born to fit into specifically designed niches. To each is given the tools of its trade. To each is given the urge to use those tools or weapons according to ancestral patterns of behaviour. In using them they employ given tactical methods. The cat stalks its prey ; the wolf chases it. As onlookers, we can see that the animals are blindly working towards a broad strategic end-plan. Their activities lead now to the preservation of the species, now to the storing of winter food, and so on. Not that they are aware of what they are doing, especially in the matter of ultimate ends. They work blindly and automatically.

With man these elements appear, but in addition he is able to understand something of what is happening. He is given to creating. Being relatively defenceless, he has, from the beginning, specialised in the making of weapons. As these are not naturally attached to his body he has had to devise methods of handling them. More modern weapons, he has tended to build around himself, as with tanks and planes.

There is here, of course, a big field of war work, namely the study of such weapons and their adaptation to the bodies, limbs and sense organs of the men who are to sit inside and animate them.

Having devised his weapons, and methods of handling them, man has had to devise suitable tactical methods of using them in action. These methods vary with the weapon, tactics suitable in the days of bows and arrows being unsuitable for use with modern firearms. At every level of development in weapons and tactics there have been problems of strategic planning. The German scheme for the invasion of France in the late war was very different from schemes possible in the days of the Romans. Finally, of course, man has long been trying to look behind the curtain, asking what kind of a plan it is that Nature herself is following.

III. Drill

Man has had to invent weapons, methods of handling them, tactics appropriate to their use, all leading to the implementing of strategic plans. He has become master of his fate to the extent that he can bend Nature to some of his ends; to the extent that he can adapt himself to circumstances.

For this he pays a price. Animals born with weapons attached to their bodies do not need to undergo the arduous drill that comes to the young human who has to practise the art of handling his tools or weapons. Long before he can use them for hunting, the youngster has to practise throwing his javelin or drawing his bow. He has to endure the tiredness and aches and pains that attend the learning process. The great violinist and the great pianist are not exempt. Of Paganini it was said he would spend hours practising just one trill.

Young animals get most of the practice they need by playing. The kitten plays with balls of wool, puppies maul one another. No one has seen a pride of lions on parade doing claw drill. But millions of individuals belonging to the master race have stood on the barrack squares of the world doing bayonet exercises. The point needs to be stressed, for although in so many ways man's intelligence places him *above* the animals, he nevertheless needs much more routine drill. It is a peculiarly human problem having its roots directly in the fact that we insist on adapting ourselves to occupations that are not dependent on inborn behaviour patterns.

It is sometimes suggested that we ought to abolish mechanical drill whether on the barrack square or in the schoolroom, teaching the youngsters to think more about their work. There is here an element of muddled reasoning. Beginners must obviously be taught the why and the wherefore. Purely blind work is wasteful. But just as no man by taking thought can add a cubit to his stature, so no man can gain facility in the arts and crafts by mere wishful thinking. One cannot learn to ride a bicycle by thinking about it. The necessary drills *must* be undergone. All we can do by taking thought (and it is a very big contribution) is to ensure that the drill is the best possible drill in the circumstances, being economical whether of time or energy. There is no need to use inefficient drills if more effective ones can be devised. And again we may note that a good deal of time was spent during the last war on this matter of training methods.

It is a curious thought that freedom and mastery of life come by way of slavery to lower order habits. But it is obvious enough in practice. No man can become master of a foreign language without long practice in it, picking up subtleties of construction, intonation, gesture, and the like. No man can be a master craftsman in iron or wood, or any other medium, unless he has has first served a somewhat painful and tedious apprenticeship. The lower animals are essentially automatic in their working. Man is a little removed from their level in that he can know what he is doing, in that he can direct his actions towards a desired end. But he is not so far advanced on the path away from automatisms that he can do without them or even take charge of more than a minute fraction of his own bodily machinery. Thus, for example, at the moment of speaking, I stand easily on my two feet letting my tongue get on with its work. I do not control it in respect of its essential actions, telling it when to move up, down, right, left. I cannot even know these details, much less write orders that would take my tongue through the process—as the soldier would say—by numbers. It just simply could not be done.

Still thinking of the processes of speech, it is very obvious that in ordinary conversation or in giving a lecture without notes, I do not know, even in my own mind, just what words are going to come from my tongue. As it were, I issue a directive to myself—talk about such and such—the necessary words and gestures and intonations of speech then coming automatically. In an obvious sense it is just as well that man has progressed so little beyond the level of automatic working. It is much more convenient to have these things 'laid on'—to use the Army term. It is much more convenient to sit back and issue orders to the body-mind machinery, saying 'Talk about this' or 'Write about that.'

It is this freedom to sit back and issue orders that is at the root of many of man's troubles. It is at the root of the muddled reasoning mentioned a moment ago, namely the argument that mechanical drill ought to be abolished. It is true that *if* I had intellectual powers strong enough and wide enough, I might conceivably be able to take charge of my body, telling my arms to do this and my legs that, when studying out new tricks in cricket or hockey. By so taking the work over into the realm of conscious control, I might not have to practise a given game so assiduously. On second thoughts, however, I personally would rather not. It is better from our human point of view to pay the price and do the necessary drills. To condemn me to a life of working out operation orders for my arms and legs would be like telling a commander-in-chief to do his own staff work. It is much more economical to leave him entirely free in order to concentrate on the broader planning required.

Drill being an essential of human life, we sometimes attach importance to out-of-date exercises. This is especially well seen in the army, where ceremonial drills, parade ground drills and battle drills compete for attention. It is seen in the tendency for church and state to stick to old rituals even when they have lost all trace of their original meaning.

All worth-while drills start as battle drill. At that stage they have a very real meaning. There are several quite good reasons why troops of to-day should form up in three ranks. Were eight or nine more convenient, that system would be adopted. Thus, for example, when firearms were first invented, they were slow in action. To get fire-power, the officers of those days devised some quite elaborate techniques ; quite elaborate drills. One such drill put the men in eight or nine ranks in open order. The front rank men, having fired, immediately doubled to the rear, passing through the open files of the men behind them. There, they reloaded. Meanwhile, the old second rank, now in front, fired, and doubled back in their turn, and so on. Or again, in the days of Waterloo, much was heard of British squares that stood up to cavalry without breaking. It was well known that a square need not be broken if the men stood firm. Battle drill of the day therefore laid great stress on the moving of men in mass. Such drill became useless when quick-firing weapons came into use. Massed movements had to give place to open order drills.

The battle drills of to-day lay great stress on the part played by N.C.O.s and men. It is sometimes said that modern industrial methods make men into mechanical robots. That may be so. But modern methods of warfare are not mechanical in that sense. As insistently as at any time in history is it demanded of men that they should pit their individual wits against the enemy.

Thus, for example, in the days of massed movements, a battalion commander could often be seen and heard by all his men. To-day, control of the individual man is in the hands of an N.C.O., the section commander ; and a pressing problem in practice is that of finding enough corporals and sergeants capable of exercising command. It is to help them that so much of their work is reduced to routine drills, where the section commander learns just what orders to give to his rifle and light machine gun groups, swinging his little army of two squads about, using his common sense in emergencies and always trying to fulfil the orders given him by his platoon commander who in his turn has to swing his three sections about to fulfil the requirements of the company commander, and so on, up through the chain of command. Always, the drill is directed towards making things work automatically. For just as man finds it most economical not to attempt to interfere with his body while it is at work, depending rather on its automatic functioning, so in building an army the essential problem is to bring in as many automatisms as possible, leaving the commanders, whether senior or junior, to devise plans and issue general orders ; leaving the private soldier time to think, time to observe, time to do what *he* must do if the desired end is to be attained. Once more, therefore, we come back to the same conclusion. Freedom only comes when lower order techniques have been made to work automatically.

Drills should change with change in conditions. The tactics of the desert were not suitable for the Normandy beaches. Units transferred from the one field to the other were given time to adapt themselves. They spent arduous months practising the art of fighting in close country, and necessarily so. To have depended on techniques learned and made perfect in Libya would sometimes have been fatal.

Although adaptation and change are essential if drills are to be kept up to date, old soldiers—like other people—tend sooner or later to crystallise in their habits. They reach a point where faith in the magic of the drills of their youth blinds them to the need for change. Essentially battle drills in their far-off youth, such drills tend to have but sentimental value in their prolonged old age. This happens in politics, in the church, in every field of life. The dynamic urge of

a new prophet, a Moses, a Booth, or a Baden-Powell leads him to create new drills. Inevitably, the followers of such a man will tend to crystallise those drills, sticking to them perhaps even in circumstances that would have made their founder devise a whole system of new drills had he been alive. The analogy is with a volcano that becomes quiescent. The lava-flows that made the first cone having solidified, the whole thing becomes static—until, with a new eruption, the old lava-flows are broken apart, and dynamic new flows are sent out, only to solidify in their turn.

In invoking the magic of old drills, people often try to justify them in terms of a formal disciplinary value. They are defended because they are supposed to inculcate some or all of the major virtues.

There is an element of truth in the notion, although it may not be clear to some of the people who put it forward. Battle drills of to-day tend to be formal (or even ceremonial) drills of to-morrow. The massed movements so typical of the older methods of fighting still persist on the barrack square. As we have said, those methods, and the drills leading up to them, had justification when they were young. Under modern conditions, the fighting methods as such are no longer useful. They are more than useless—they are dangerous. But that need not apply to the corresponding drills. May they not have retained some of their usefulness? If they induced things like steadiness and self reliance in the years that have gone, will they not do so to-day?

As is now well known, formal discipline or transfer of training takes place because of common elements. If the skill acquired in a chemical operation transfers in the sense that it makes the student learn a physical routine more quickly, that transfer must have taken place in virtue of a common element in the two performances. As we have seen, there are common elements in many groups of tasks. There is a corresponding element of truth in the notion of transfer of training. It is not strong enough to justify the rule that old drills should be kept on just because of possible disciplinary value. One can teach (or rather inculcate) self reliance even better with modern battle drill than with parade ground drill. But as long as we keep the battle drills of our given age as up to date as we can, as long as they are fluid enough to be readily adapted to new moves in the game, we need not worry about a certain amount of sentimental regard for the older rituals. After all, we still have archery and javelin throwing in the list of sports. It would be unwise to say they do not benefit those who practise them.

IV. Factor Studies

Working up through the notion of man as the creator of weapons and methods of handling them, we have looked at the problem of reducing his techniques to the automatic level. We have not looked at the measures made when studying these things.

I can illustrate in terms of a few figures obtained during routine Home Guard testing. It did occur to me to borrow a few figures from the regular Army, but as our present object is merely to illustrate the kind of tables to be expected, my own will serve.

A battalion covering the northern part of Cardiganshire was involved. Of about 1,200 officers and men, several hundred presented themselves for test or re-test during the last year of the Home Guard. We can note therefore that the men were keen, the whole thing being voluntary. When the first 170 men or so had been tested, correlations were calculated as in Table I.[1]

Table I

	G.K.	Gren.	Maps	B.C.	Rifle	O.W.
General Knowledge	X	·46	·38	·49	·48	·36
Grenades	·46	X	·42	·41	·47	·24
Maps Reading	·38	·42	X	·50	·31	·38
Battle Craft	·49	·41	·50	X	·39	·16
Rifle	·48	·47	·31	·39	X	·21
Other Weapons	·36	·24	·38	·16	·21	X

As shown in the Table, each test tends to correlate with each of the others. The coefficients get smaller as we go down the table (it was arranged so as to get the biggest values in the top left hand corner) but, nevertheless, there is correlation everywhere. In other words, men who did well in one test tended to do well in all; men who had trained well in one tended to be well trained in all. There was an element of all-round efficiency.

The men were shepherds from the hills, farm servants from the valleys, with townsmen of all trades and professions. One of the first men to get top marks in all six tests was a shepherd from the slopes of Plynlimmon. Just what was there about him that made him excel? One obvious answer would be the possession of all-round general ability, and that was probably the main factor. Many of us would say that depended mainly

[1] If two class lists agree perfectly the correlation is maximal with r = 1·00. If it is perfect but inverse, the man top in one list being bottom in the other, and so on, then r = − 1·00. If there is no relationship, r = 0·00.

To read the table look along the row or down the column headed by the name of the test in question.

on the something more usually called intelligence, and again, the answer is probably right. Some of us might call it all-round adaptability, for he had obviously adapted himself to play each and every one of the parts open to him in our part-time soldiering, and that despite his normal preoccupations. Looking at the table as a whole, and asking just what would be the cause of the correlations we get, of course, the answer we have just given for the single individual. Running through the work of all the men must have been these general tendencies of all-round ability, adaptability, and so on, tendencies tending to push the better all-round men to the top ; tending to push the weaker men down in every list.

Stray factors of less desirable nature must also have entered. Men presenting themselves for test before their training was adequate probably got low marks all round, that, of course, introducing a general tendency within the meaning of the term, for *any* factor causing an individual to act in the same way from test to test is, *ipso facto*, affecting the work 'generally.' Summing up, therefore, there must have been quite a few different things acting generally, so that we must not regard the 'general factor' of such a table as representing or deriving from a single mental entity or power or 'gift.' It is the sum total result of a complex of tendencies.

A question arising during testing was whether the older soldiers (especially those of 1914–18 vintage) would do better in the more mechanical tests, as, for example, those with the rifle. It was felt that maps and battle craft would be things in which the younger soldiers might have fewer prejudices to combat ; in which they would be nearer the Boy Scout level.

It was not possible to go into each man's history. It was therefore assumed that we could get the necessary information by correlating with rank, the notion being that the older soldiers would be N.C.O.s. The results are seen in Table II. Reading them,

TABLE II

	G.K.	Gren.	Maps	B.C.	Rifle	O.W.
With Rank .	·28	·50	·24	·19	·46	·43
Saturation with General Factor	·74	·65	·66	·67	·62	·41

it should be noted that if (on the average) the N.C.O.s are better than the privates, the correlation with rank will be positive. If the privates are better (on the average) the correlation will be negative. If there is nothing in it, the correlation will be negligible or zero. As will be seen, all six correlations are positive. In all six tests, therefore, the N.C.O.s did relatively better than the privates.

It is interesting that, as some had expected, the advantage to the N.C.O.s was greatest in respect of weapons and least in General Knowledge, Maps and Battle Craft. We must be careful however in interpreting the fact. Superiority in weapons *might* be due to a more mechanical interest. It might, however, be due to maturation. For as James has said, we learn to skate in summer and to swim in winter. Going back to the ranges after a quarter of a century many of the old soldiers were surprised that their ability to find the bull was not impaired by the lapse of time, to any very obvious extent at any rate. Or again, smallness in the difference between N.C.O.s and men in Map Reading and General Knowledge might have been due to the fact that the tests were oral, or largely so. Even a recruit will pick up quite a lot if the teaching and testing is by word of mouth. The smallest advantage to the N.C.O.s was in respect of Battle Craft. Here I am disposed to argue that age may have affected the results. The sight of a portly Sergeant Mucklewame demonstrating how to cross a gap in a hedge or to take cover behind a bush is not always convincing. The more agile youngster is more likely to look the part.

It may be asked how strongly or in what measure the general factor is manifested in such Tables as that here shown. The required measures are given in Table II under the name 'saturation coefficients.'[1] As will be seen, the General Knowledge test is most saturated with the general factor, 'Other Weapons' being least saturated. In other words, scores in General Knowledge were determined largely by all-round ability, whereas scores in Other Weapons were determined more by specific factors.

The results we have been discussing were from tests of training. The same kind of analysis can be applied to tests of potentiality as used in the selection of recruits.

It is important to notice the difference. When testing recruits the task is to advise on the kind of training suitable for individual men. When testing *after* training we are assessing not merely the goodness of training as such but the efficacy of the selection procedures by which the men were chosen. For, clearly, a heavy failure rate in the school is a reflection on the methods of admission, and

[1] Saturations are themselves correlations. They show the extent to which the class list in the given test would agree with an ideal order of merit determined by the general factor as such.

that holds whether in a training regiment or a civilian educational establishment.

It is not necessary to quote actual tables of correlations for results from selection tests. They are of the same general nature as Table I. They can be analysed in terms of general and group factors. As in tests of training, the general factor is largely determined by all-round ability, but other elements may enter.

If, e.g. the man is lazy, it may result in his losing marks all round. In the main, however, it seems fairly certain that the general factor in a table from selection tests will be much the same as that found in tests of training. The man of all-round ability will tend to be at the top when he is a recruit; he will tend to be still at the top when he is a trained soldier. And similarly for men of low ability, they will tend to be near the bottom whether at the one stage or the other. We are speaking, of course, of tendencies. There will not be perfect correlation between standing as a recruit and standing as a trained soldier. Much work has been done in an attempt to show how closely they do agree. For, clearly, one of the main functions of the selection test is to predict where the man will stand after training.[1] And if the general all-round factor is the one determining trainability as well as selection, we have put a name to the biggest element in the complex.

Having thus briefly surveyed some of the problems of war-time psychology in the Army, we may close by glancing at a problem that will be exercising the minds of many of us for some years to come. The new Education Act for England and Wales says that children shall be given the education demanded by their ability and needs. To determine just what each and every child needs in a population of millions is a colossal task. It is not a matter of selection. It is a problem of guidance, for each child must have what is best for him.

What now *is* best for a given child? Trying to envisage a perfect scheme, it becomes apparent that just as in the Services or in Industry men must be employed in jobs appropriate to their respective levels of all-round ability, so in educating children, the classes or groups in which they are taught should be nearly enough homogeneous for all-round ability or—as the teacher usually calls it—intelligence. It is so often a tragedy when a child gets into a school above his general level. He has to struggle to keep up; inevitably he must fall behind. He may develop inferiority feeling; he may become a delinquent. Many things may happen. Analogously, if he is in a group much below his general level he will not be extended, and again there may be repercussions.

In other words, we need schools ranging in level from the typical Grammar School for children destined to go to the University down to special schools for mental defectives. How many different levels we need between those extremes is a matter to be settled in the given neighbourhood. A big city has different problems from those of a sparsely inhabited rural area. The exact details do not, however, matter as much as the general principle, namely that the first consideration is this fitting of schools to given levels of intelligence.

Within his stream or level, the child should be given a course of study suited to him. It is here I feel doubtful about some of the suggestions current at the moment. It is thought by some that we ought to use tests to pick out children of technical ability. But just what *is* that ability? It sounds suspiciously like one of the old Faculties. In any case, tests will only give a rough indication. An inquiry into the child's hobbies and past interests or training would probably give the same information in more explicit form.

I myself at 10+ had quite a lot of technical skill. I should probably have seemed an obvious case for technical education, I should probably have passed all the tests. It was not necessarily because of anything inborn. It just so happened that I got into the habit of frequenting the workshops. I learned how to sew in leather and could mend any bit of harness I could hold in my lap. The wheelwright had a little brush and a small paint kettle that I called my own. I did a lot of painting for him. I was not allowed to shoe a horse, but in the forge I could turn out quite useful horseshoe nails, hammering them down from a length of iron rod. All these were skills acquired because of the accident of my environment. Ought I therefore to have gone to a Technical School? There was quite a good one near by. In fact, I had absolutely no desires that way. I was determined to be a teacher and a teacher I became, despite all advice to the contrary.

[1] A good deal of 'Follow-up' work was done during the war. Representative samples of men were traced from the recruit stage to the end of their training to see whether the story told by selection test results would be borne out by the routine reports made on them by instructors in the training units. In some cases, follow-up work was carried out on Active Service, men being traced to their fighting units. This last kind of work applied especially to young officers. As will be realised, the selecting of suitable candidates for commissions is an important task in modern warfare. Much time and thought was spent on the problem, new methods of selection being tried out, adopted or scrapped, as the case may be, and elaborate follow-up schemes being put into operation.

Desire and determination are factors not measured by tests. They come out when we make a study of the child, his likes and dislikes, his background, his early hobbies, and so on. I ought perhaps to have entered the Technical School ; I ought perhaps to have become a saddler, a fitter, or a builder. But the notion of what *might* have been supplies no proof that it *ought* to have been. That I have succeeded more or less as a teacher is no proof that I was better fitted for it than for anything else. To think or argue in that way would be to deny the one fundamental fact of facts, namely that man is adaptable. It would be to deny that John Jones, bank clerk, should or could or ought ever to become John Jones, tank gunner. Man in his time plays many parts. If he had more time he could play more parts. Always provided those he tries lie within the limits of his all-round ability. Always provided he has the necessary grit and determination to go through the necessary drills ; to serve the necessary apprenticeships.

SECTION K.—BOTANY

THE HISTORY OF PLANT FORM

ADDRESS BY

DR. H. HAMSHAW THOMAS, M.B.E., F.R.S.

PRESIDENT OF THE SECTION

IN addressing you to-day I must first, as in duty bound, remind you of those officers of Section K who have passed from us since we last met.

Sir Albert Seward, who was President of the Association when it last met in Dundee, had been an active member of this Section since its creation in 1895. He occupied the presidential chair in 1903 and again in 1929, while he contributed papers on many occasions. Both of his presidential addresses dealt with extinct floras, considered especially as regards their distribution in space on the earth and in contrast to the distribution of the world floras to-day. This subject was Seward's main scientific interest, and in pursuing it he made contributions of the greatest value to all aspects of knowledge about the plants of past ages.

At the first meeting of our organising committee after the war the chair was taken by Miss E. R. Saunders, who died later in the year as the result of an accident. She had attended the meetings of this section with great regularity for many years, and she was our President in 1920. In her presidential address she dealt with the position of genetics, and surveyed the theories which had then been recently put forward by Morgan as to the rôle of the chromosomes in the transmission of hereditary characters. She concluded that there was a very close correlation between chromosome behaviour and the phenomena which she had discovered in the course of her experiments in plant breeding. This may be regarded as the first official recognition in this country of a theory now universally accepted, and also of the importance of cytology in genetical investigation. We must always remember that Miss Saunders began her work on plant breeding in 1895, before the rediscovery of Mendel's work, and that much of the routine practice of workers in plant genetics was due to her.

Sir John Bretland Farmer was President forty years ago. He was a great teacher and organiser, whose name will be remembered as one of the first workers in cytology in Britain.

Dr. F. F. Blackman was our President in 1908. He and his pupils made many contributions to our proceedings. His important contributions to botany are well known, and his influence on the development of plant physiology has been very profound. As a student attending his lectures he brought to me a new outlook on plant life. Physiological processes were shown to be reactions in a complex physico-chemical system rather than manifestations of the obscure vital activities of protoplasm. This concept had an influence which extended far beyond the confines of plant physiology.

Sir David Prain presided at Winnipeg in 1909. In his earlier years he carried out important taxonomic work on the flora of India and developed the cultivation of plants of economic importance. Later, as Director of Kew, he was distinguished as an administrator while contriving to continue his taxonomic work. The development of plant studies in the Empire owes much to his wisdom and energy.

Professor J. H. Priestley, President in 1932, was intensely interested in every aspect of plant life, and his originality of outlook had a stimulating influence on those who knew him. He was an active supporter of this section and often contributed papers at our meetings. I believe that he has had a lasting influence in promoting the integration of different aspects of botany, and in linking together physiological and anatomical considerations.

Professor Lloyd Williams was too rarely seen at our meetings but was our President in 1925. He was a first-class botanist, and his investigation of Dictyota, with its important implications, will always remain a classic study.

We must also remember one of our former Recorders, Dr. Ethel Miles Thomas. For

about thirty years she was constant in her presence at our meetings, she contributed papers on the anatomical problems which formed one of her major interests, and after being one of the secretaries for the Australian meeting in 1914 she was Recorder from 1919 to 1921.

If you read the addresses delivered by the presidents of this Section in the past, or examine some of the older botanical journals, considerable changes will be noticed in the subjects which have formed the centres of botanical interest at different times. It seems fair to say that in recent years there has been a marked tendency towards an integration of the different branches of our subject, with more attention to the study of plants as living organisms. This has led to a gradual closing of the gaps which formerly seemed to separate the work of taxonomists, morphologists and physiologists, largely owing to concepts introduced through the study of ecology, cytology and genetics. Even the study of the plants, which have been long dead and extinct has been influenced, in that we are now approaching them as the remains of forms which were once alive and whose structures were related to the environmental conditions under which they grew.

Evolution and Modern Botany

In view of these changes in outlook, an address on plant evolution may seem at first sight out of fashion. But even though our thoughts may be mainly centred on the problems presented by the plants now living, there are few botanists who can repudiate all interest in the question of how the present vegetation of the earth has come to be as we find it. Evolution now holds a place in Biology as fundamental as the concept of atoms and molecules in Chemistry. Students are taught about evolution at school in the earlier stages of their biological training, and it has come to be held as an article of faith. Several branches of modern botany are largely based on the belief in evolution as a fact, and every branch has been influenced by the concept to a greater or smaller extent. Much progress seems to have been made towards an understanding of the possible mechanism of evolution, but little or no progress has been achieved in proving by the production of actual historical evidence that evolutionary changes have taken place in the form and structure of plants. Can we truthfully say that we know very much more about the history of the flowering plants and the fungi, the two largest groups of living plants, than was known in Darwin's day? Much has been discovered about the form and structure of extinct plants, but there is little certainty as to how this knowledge bears on origin of living types. While such ignorance exists there must always be a strong tendency among botanists to regard the hypothesis of evolution as a dogma which must be believed in the absence of any other reasonable hypothesis, in spite of the absence of any direct or decisive evidence. Such a position has a pernicious influence on botanical thought, by encouraging deductive and subjective reasoning, in place of a critical objective outlook and the active pursuit of research. Few attempts have been made during the last quarter of a century to survey the historical records bearing on the past history of the flowering plants, and since so little general agreement has been reached by studies on fossil or recent forms, I have chosen to speak about this subject to-day.

Interpretation of the Geological Record

New knowledge of the plants of the past has come in a steady and ever increasing stream since Darwin's day. Our zoological colleagues have produced series of fossil animals which seem to give the strongest direct support to the evolution hypothesis. Why has so little emerged from palæobotanical work? There are perhaps several reasons for our failure. First, because the interpretation of the fossil record has been too largely a deductive process. Many botanists have been satisfied that they know from studies on living forms how plants had changed in the past, they then sought for evidence of the changes which they had imagined. We have been unable to find ancient plants of the types which were being sought, very probably owing to the simple fact that no such types ever existed. We have been like the man searching in a dark room for a black hat which was not there.

Then again, many of the plants found showed considerable differences from modern types, but their forms and structures were interpreted by reference to the subjective concepts of plant form which originated in the 18th century and were popularised by Goethe's able advocacy. Although Dr. Agnes Arber (1925) pointed out that a clear distinction should be made between evolutionary (applied) morphology and pure (typological) morphology, we did not perceive the implications of this distinction.

The philosophical foundations of the evolutionary and typological aspects of morphology are distinct, and we must not apply the terms and concepts of typology to the study of evolutionary problems unless it

can be shown that the structure of historically primitive types was identical with the subjective concepts of the 'urform.' I would suggest that the introduction of the concept of the sporophyll into evolutionary morphology and palæobotany has been largely responsible for obscuring the position, and rendering an integration of all the relevant facts impossible. The logic of plant morphology needs very careful scrutiny, and in my view, the disappearance of the term sporophyll as applied to the seed plants will greatly clarify the position. I do not wish to suggest that typology or pure morphology is a valueless study, but only that we should realise that it rests on certain premises and definitions, and these are generally different from those held by botanists interested in evolutionary studies. It may be that a similar caution should be employed in evaluating the concepts derived from developmental and ontogenetic studies, which have been also frequently influenced by the preconceptions of their authors. Some day in the distant future it may prove possible to integrate all aspects of morphological study, a hope which is strengthened by some of Mrs. Arber's recent studies (1941).

A second source of obscurity in the treatment of our problems has arisen through the acceptance by palæobotanists of the same units of geological time as are employed by geologists. The chief geological periods represent epochs of more or less continuous marine sedimentation when deposits characterised by similar marine organisms were laid down. At the end of each period uplift occurred and a terrestrial period intervened, resulting in changes in the marine faunas and unconformities in the sequence of sediments. But our plant fossils belong to those periods of uplift; consequently palæobotanists should use divisions of geological time which are complementary to the periods of marine sedimentation. Thus it has long been known that the fossil floras of the Upper Devonian rocks were scarcely distinguishable from those of the Lower Carboniferous rocks, while both floras were distinct from those of the Upper Carboniferous. The floras of the Upper Carboniferous and Lower Permian were alike, those of the Upper Trias are hard to distinguish from those of the Lower Jurassic, the floras of the Upper Cretaceous closely resemble those of the Eocene but are very different from those of the Lower Cretaceous, and so on. If we neglect this, and consider together all the plants of the Carboniferous period, or all the plants of the Cretaceous period, the historical sequence of changes in form and structure becomes much less obvious. We need also to pay strict attention to the actual time intervals between our plant-bearing rocks, as indicated by those who have investigated the radioactive minerals and the other aspects of the age of the earth. This is because the recent advances in genetics suggest a connection between the rate of reproduction of a race of plants and the number of changes in its genetical constitution which are likely to occur.

Most of the authors who have attempted comprehensive surveys of plant evolution have taken the present-day plants as their starting-point. They have attempted to trace the history of each group backwards into the distant past. If the fossil record contained abundant remains of each type from every period this might prove a useful mode of work, but the evidence at our disposal is far from being complete and continuous. The conditions under which plant remains can be preserved are strictly local. It seems probable that most of the forms known to us belonged to communities growing on or near the shores of freshwater lakes, estuaries or deltas, or in places which were overwhelmed by the water from geysers or hot springs rich in dissolved minerals. Such plants are likely to represent only small samples of the earth's vegetation at the time when they lived, and the fossilised forms may only be samples of communities living near the place of their entombment. The very frequent discovery of types not previously known shows, moreover, that even our knowledge of the forms which were preserved is far from complete. Thus the chances of our being able to trace the actual phylogeny of any species, or perhaps of any larger taxonomic group, are very remote. Under these circumstances the attempt to link living forms with their more remote ancestors must become partially or entirely a subjective process. We form ideas as to the structure of the ancestral types and attempt to discover among our fossil remains specimens which conform to these ideas.

My friends have often advised me to concentrate on the search for early angiosperms as a surer solution of the great problem of plant evolution than the reconsideration of our existing knowledge. But how am I to recognise a very early angiosperm ancestor if I happen to find one? Only by drawing upon my imagination of what a primitive angiosperm was like. If the fossil record is to be used for the purpose of discovering the manner in which the form and structure of plants changed during past ages, we must relinquish such deductive reasoning and observe the actual sequence of changes as we pass from the older rocks to the more recent deposits. We must examine the

fossil forms as the remains of living organisms, which almost certainly had a physiological constitution like the plants of the present day and were similarly affected by the external conditions of their environment. The reference of our extinct forms to morphological patterns is of far less value. It may indeed hinder our appreciation of the facts rather than help us to understand them. For this reason I not only reject the application of the old concepts of morphology to extinct forms, but I hesitate to apply the concepts of the *phyllome* and the *telome* which Zimmermann (1930) has put forward. While these recent terms may be useful in the description of some early genera, it has yet to be shown that they are of general application : their use as categories of universal significance will again introduce deductive reasoning which ought to be avoided.

While it is impossible to trace real phylogenies, we have material which shows us in a general way how the forms or characters of plants changed from age to age. By comparing all the plants of any one age with each other, and with those of earlier and later periods, certain types of structural change become clear, such as from the much divided frond to a simple type of leaf. We also find good evidence that parallel evolution has taken place in different groups. This type of study, which has been termed character phylogeny, was advocated by Nägeli as long ago as 1884, but has received less attention than it merits. Critics may say that the evidence, even for this type of investigation, is too incomplete ; but it should be remembered that such a study of the history of plant form has much in common with the study of the earlier periods of human history. The historian of human societies has to work with incomplete and fragmentary evidence, nevertheless his work is of value, if pursued objectively, in providing a way of linking together all the known facts. Our studies on the history of plant form will not at once reveal the whole truth about vegetable evolution, but they do provide evidence of changes in structure with the progress of time. This can furnish a basis for theories that will be modified from time to time as more facts become known, and can be compared with the results of studies on living forms.

The Forms of the Early Vascular Plants

Our earliest records of vascular plants date back to a period some 400 million years ago. When we review these plants from the Upper Silurian—Lower Devonian rocks, made known by the researches of Lang, Cookson, Krausel, Weyland, Halle, Hoeg, Stockmans, and others, we find evidence that plants once existed that were substantially different from those of the present day. At least fourteen distinct types of vascular plants are now known, whose characters are very unlike all modern forms. They may be placed in three groups on vegetative characters :

Smooth forking axes without leaves.	9 genera.
Branching stems with spine-like emergences without vascular strands.	3 genera.
Stout axes with microphylls having vascular strands.	2 genera.

The remains of these forms have been found in several widely separated parts of the world. Their examination points to the conclusion that many of the primitive land plants had forking vegetative axes without well-defined distinction into stems, roots and leaves. They were very like the later *Rhynia* which has been so thoroughly investigated by Kidston and Lang. Before the discovery of *Rhynia* the existence of plants of this general form was postulated by Lignier as the ancestral type from which megaphyllous species arose, and his hypothesis has since received much support as is shown in Paul Bertrand's posthumous book (1947).

The Middle Devonian flora, which may be some 30 million years younger, shows much greater vegetative differentiation. At least twenty distinct forms have been found. These may be grouped as follows :—

(*a*) Smooth branching photosynthetic axes.	6 genera.
(*b*) Stems with non vascular emergences.	2 genera.
(*c*) Stems with microphylls.	2 genera.
(*d*) Stems with small, lateral, dichotomously divided leaves.	3 genera.
(*e*) Stems with deltoid leaves having forking veins.	4 genera.
(*f*) Stems with large, spreading, frond-like organs composed of repeatedly branched narrow segments.	3 genera.

The continued presence of a majority of forms with smooth axes appears to confirm the view that this is one of the very primitive types. The microphyllous types (Class *c*) seem to be the forerunners of the Lycopods, of which there is almost continuous evidence up to the present day. The forms in Class *d* (*Hyenia*, *Cladoxylon scoparium*, and *Calamophyton*) should perhaps be regarded as of

a distinct morphological type, since their lateral appendices seem to have the character of photosynthetic organs and to resemble leaves in their limited growth, but show dichotomy into equal parts to a greater or less degree. We may feel fairly certain that here we have forms from the like of which the Sphenophyllales and Equisetales originated, but some of the large-leaved plants may have come from this type also. The plants in Class *e* are still imperfectly known, but the type named *Barrandeina* with both fan-shaped and narrow once-forked leaves may represent the common ancestors of the Ginkgoales and Coniferales. Class *f* seems to contain types like those from which the ferns and pteridosperms sprang, as suggested by Lignier.

Upper Palæozoic Seed Plants

The plants which are found in the Upper Devonian to Lower Carboniferous rocks show still greater variety of vegetative form. The microphyllous Lycopods reached considerable size and importance as constituents of the vegetation of the swamps, while the huge trunks of gymnosperm-like plants occurring in Scotland, Northumberland, in New York State and elsewhere, suggest that large trees of coniferous appearance and structure occupied the drier ground. The primitive type of construction seen in the Lower Devonian *Zosterophyllum* and the Middle Devonian *Rhynia* has almost disappeared, though *Stauropteris* and possibly other forms like *Botryopteris antiqua* still seem to have been mainly composed of smooth branching axes. In the megaphyllous plants considerable changes are found. A wide variety of types has been recognised from impressions and from mummified examples of parts of fronds. In a few of these the much branched segments into which the frond was divided were still narrow and axis-like, in others the ultimate segments or pinnules were slightly expanded, deltoid or spathulate. Sometimes they were lobed, but we seldom or never find compact fronds with broad closely set pinnules as in the Upper Carboniferous. It is at present impossible to distinguish between the early ferns and the pteridosperms in this kind of material. Petrified remains of stems and petioles show that a number of plants with structure that can now be associated with the seed habit occurred during this period. Six or more different types show centripetal wood, secondary wood, a characteristic outer cortex with bands of mechanical tissue, and somewhat distant leaf traces. The archaic centripetal wood generally contains a mixture of tracheides and parenchyma in the medullary region, but the smaller axes may have a solid protostelic structure. The structure of the leaf traces and petioles is consistent with the view that the fronds represent specialised photosynthetic side branches, but in several forms the petiolar structure had become widely different from that of the main stems.

The Pteridosperm fronds of the Upper Carboniferous—Lower Permian epoch show a more advanced stage in the enlargement and consolidation of the photosynthetic areas. Types with narrow ultimate segments had almost disappeared, and the well-known forms called *Sphenopteris*, *Neuropteris*, *Alethopteris*, *Mariopteris*, etc., were represented by many species. The pinnules expanded rapidly from their bases, or the base of the lamina was concrescent with the pinna axis. They had a close, spreading, but open venation. Towards the frond apex pinnules and pinnæ became concrescent, indicating a tendency towards the consolidation of the lamina. Most of the frond forms found in the uppermost beds of our Coal Measures suggest greater photosynthetic efficiency through an increase in the size of the pinnules. In two or three groups reticulate venation appeared, and the general trend of leaf architecture seems to have been much the same as Bower (1923) has suggested for the ferns.

The humid climate under which our coal was probably formed seems to have persisted during the Lower Permian time in China and parts of North America where the interesting fronds named *Gigantopteris* are found. This genus shows advances in leaf form which suggest a linkage between the pteridosperms and the dicotyledons. Professor Halle (1929) has reviewed the facts about these leaves or fronds which he refers to the Pteridosperms. Some were huge compound leaves with large leaflets and a terminal segment of concrescent pinnæ, others were broad, ribbon-like, entire leaves, perhaps representing a second genus. All had a reticulate venation, and the leaflets of the compound form were compared by Schenk, in 1883, with the leaves of *Nicotiana*. Halle has found specimens suggesting that the plants which bore these leaves were lianes. Another approach to the leaf form now characteristic of the dicotyledons is found in two characteristic genera widespread in the Southern Hemisphere during the Permian period. These are the well-known types *Glossopteris* and *Gangamopteris* which, in spite of their names, were probably the leaves of seed plants. They show a considerable reduction in total area when compared with a Coal Measure pteridosperm frond, being simple in form

with an entire margin and reticulate venation. It seems quite certain that the climatic conditions under which these plants grew were very different from those of the Coal Measure period of the Northern Hemisphere. They formed major constituents of a very small flora which was widespread after the disappearance of very extensive ice-sheets, and they are accompanied by petrified coniferous stems showing annual rings.

Thus, if we take the evidence at its face value, it would appear that plants with leaves not far different from those of the dicotyledons appeared in the world at the close of the Palæozoic epoch.

Our knowledge of the progress of stem structure in large-leaved seed plants towards the end of the Palæozoic is unfortunately small, and further investigations are needed. It seems clear that a number of distinct types of stelar structure arose, and that considerable departures took place from the common type of the Upper Devonian—Lower Carboniferous period. The various forms placed in the stem-genus *Medullosa* present wide variety, if all the Permian forms from the Chemnitz area are correctly included in this genus. In some of them we find a considerable increase in the relative size of the decurrent petioles, and a great increase in number of the petiolar vascular bundles, while the stele of the main axis remains small, divides into distinct parts, and often shows strange complications. I find it difficult to resist the idea that these forms may yet provide a clue to the origin of some groups of the monocotyledons.

Although no pteridosperm stem is known which had all the characters which appear in those dicotyledons now thought to be primitive, yet in some respects the well-known *Lyginopteris* presents a type of structure approaching that from which dicotyledon stems might have sprung. Mr. Henry Andrews (1940) showed that it had heterogeneous rays and very long tracheides in its cylinder of secondary wood. The recent investigations of Dr. Dormer (1945) on living dicotyledonous stems suggests to me their original derivation from types with centripetal wood that formed a connection between the three bundles in the leaf trace. But *Lyginopteris* has tracheides with multiseriate pitting and single leaf trace bundles, so it cannot be regarded as closely related to the ancestors of the flowering plants.

Nevertheless, the fossil record as a whole suggests that during the last 200 million years of the Palæozoic era there were changes in the form of the vegetative body of plants by which types with roots, stems and large leaves, comparable with flowering plants, arose from simpler structures.

The Origin and History of Flowers

Under the influence of Goethe's doctrine of metamorphosis and of the botanists who developed comparative plant morphology in the 19th century we have been accustomed to think of plants as composed only of stems, roots and leaves. The sporangia and seeds were merely structures that were produced on the leaves or on modified leaves. But the evidence of the early fossils leaves little room to doubt that the reproductive structures were differentiated long before the plant body became specialised into the three main parts which are usually present to-day. It seems likely that from a very early stage the life-cycle of plants has been divisible into a period of vegetative growth and a period of reproductive activity. In the older forms the differentiation of the sporangia near the apices of branches was the major change in structure during the growth of the individual. It seems therefore logical to consider the fossil records of the form of the fertile branches, regarding them as separate entities whose changes in shape and structure were often independent of changes in the foliage leaves.

In earliest known land flora from the Upper Silurian—Lower Devonian period we find the following types :—

(*a*) Fertile axes bearing terminal groups of sporangia. (*Psilophyton ; Hedeia ; Yarravia ; Dawsonites ; Tæniocrada*).	5 genera.
(*b*) Fertile axes of limited growth bearing many lateral sporangia. (*Zosterophyllum ; Bucheria*).	2 genera.
(*c*) Fertile axes bearing a single terminal sporangium (*Sporogenites ; Cooksonia*).	2 genera.
(*d*) Lateral sporangia borne on stems of unlimited growth. (*Baragwanatha ; ? Gosslingia*).	? 2 genera.
(*e*) Sporangia produced on microphylls. (*Drepanophycus ; ? Protolepidodendron*).	? 2 genera.

This division may be regarded as somewhat artificial on the grounds that the forms in classes *a* and *b* bore their sporangia on the ends of short branches and were therefore essentially similar to the two forms *Sporogenites* and *Cooksonia*, but I think it important to remember that the multiplication of sporangia on the fertile shoots is an early feature and that we should not base our ideas of early fertile shoots merely on the *Rhynia*

type. Passing to the Middle Devonian floras we encounter several types whose fertile structures are as yet incompletely known but we may group them as follows :—

(*a*) Fertile axes little branched with one or two terminal sporangia on each branch (*Rhynia ; Hornea ; Asteroxylon ; Hicklingia*).	4 genera.
(*b*) Fertile axes with many lateral branches bearing terminal groups of sporangia. (*Hyenia ; Calamophyton ; ? Cladoxylon*).	3 genera.
(*c*) Groups of sporangia with slender stalks on frond-like lateral branches (megaphylls). (*Aneurophyton; Svalbardia; Protopteridium*).	3 genera.
(*d*) Single sporangia on the surface of microphylls (*Drepanophycus ; Protolepidodendron*).	2 genera.

Here again the production of sporangia at the ends of fertile shoots predominates over the production of sporangia on leaves. While in some of the forms distinct fertile shoots were differentiated sharply from the vegetative shoots (class *b*), a feature which was to characterise the later Sphenophyllales and Equisetales, in others the fertile and vegetative shoots were not so distinct. The development of the photosynthetic fronds in the plants of class *c*, sometimes involved fertile branches, which appeared in different parts of the frond. Ferns and pteridosperms may have originated from such types.

During the next terrestrial period, comprising rocks dated as Upper Devonian—Lower Carboniferous, we have better evidence of the existence of seed plants with large leaves, and consideration of the other groups can now be omitted. The fine work of Robert Kidston, of Stirling, whose name should always be remembered in Scotland, provided detailed information about the fertile structures from the Lower Carboniferous rocks which is of great morphological interest. He described (1924) six kinds of pollen-bearing structures, all of which showed groups of elongated sporangia borne terminally on fertile shoots. In *Telangium* the sporangia were 2.5 to 3.5 mm. long and were borne on terminal discs or cup-like receptacles ; as many as 25 sporangia were present in each little cluster. *Schuetzia* had much longer sporangia on terminal discs. *Diplotheca* had discs with 5 pairs of linear sporangia about 1 cm. long and 1 mm. wide. In *Alcicornopteris* there were many sporangia each about 1 cm. long forming flower-like groups about 2 cm. broad, and *Pteridospermostrobus* probably had a similar construction. An interesting new type discovered by Prof. Walton (1931) and called *Diplopteridium* may also belong to the same group.

All these structures grew on the ends of branches devoid of leaflets ; in *Diplopteridium* the forking fertile axis was a branch of a photosynthetic frond.

While I am sure that many other early pteridosperms existed at this period whose fertile structures are unknown, we cannot neglect the uniformity of plan which is seen in all the known forms. Putting aside all questions of theoretical morphology, these structures more nearly resemble the male flowers of angiosperms with unisexual flowers than any other structure in the plant world of to-day.

It would seem almost certain that in these early plants the seeds were borne on distinct branch endings, but most of the known seeds have been found as isolated specimens. All show evidence of radial construction, and all exhibit to a greater or less degree the separation of the integument into a number of free lobes above the level of the nucellus. Professor Gordon's remarkable demonstration of the structure of *Salpingostoma* (1941) shows this in a striking way. The majority of these seeds are known to have grown inside radially constructed envelopes generally known as cupules, and a specimen (*Calathiops Bernhardti*) described by the late Dr. Margaret Benson had branches like an inflorescence with terminal cupules containing several seeds.

The fertile structures of the Upper Carboniferous—Lower Permian pteridosperms were at first given interpretations in terms of the older morphological ideas which scarcely did justice to the facts. But much recent knowledge has been obtained, largely by Professor Halle (1933), which brings the pollen-bearing structures into line with the older forms and makes their interpretation as marginal sporangia borne on a fertile pinnule untenable. Almost all the known microsporangia were produced in groups at the tips of branches. *Telangium Scotti* shows such a group in petrified material, other similar forms have been found in coal balls but not yet described. *Crossotheca Kidstoni*, according to Kidston, had a broad terminal disc, generally becoming recurved and bearing a whorl of radially arranged bilocular synangia. Halle showed that the forms *Codonotheca ; Boulaya ; Whittleseya ; Aulacotheca* ; and *Goldenbergia*, were radially constructed structures in which the sporangia

were more or less concrescent, *Zeilleria* showed concrescence of microsporangia of a different form, while *Potoniea* had a cup-like terminal receptacle on which many elongated sporangia were borne. The simplest interpretation of these forms would derive all of them from the earlier structures which I called male flowers. Some of them like *Aulacotheca* had already diverged widely from the Lower Carboniferous types and subsequently died out, others, viz. *Crossotheca* and *Potoniea*, had become still more like the angiosperms in their general appearance.

We have very little information about the way in which these pollen structures grew. Some were borne on branching stalks which may be called inflorescences. In *Crossotheca* they were on frond-like branches with photosynthetic segments below, while in *Zeilleria* they occurred on the margins of pinnules. The same is true as regards the seeds in the group. Forty or fifty years ago it was thought that the seeds of the Pteridosperms would be found to occur on the fronds in the same way as the sori of the ferns. In spite of careful search this belief has not been justified, on the contrary we can be certain that the occurrence of seeds on the photosynthetic fronds of the Upper Palæozoic pteridosperms was an exceptional phenomenon. According to our present knowledge the seeds were most commonly borne on separate flat branching systems which did not bear normal pinnules. We do not know the manner in which these were connected with the main stem. A few examples have shown a seed on a short branch at the apex of a pinna or of a frond with normal vegetative pinnules below. One or two forms have been discovered with seeds on the surface of the pinnules of a typical frond.

When Professor Halle reviewed the evidence in 1935 he suggested that the evolution of these primitive seed plants may have proceeded along two separate lines. In one the seeds and sporangia becoming localised on the leaves in a way parallel to the ferns, in the other the plant body was differentiated into a vegetative and reproductive region, the fertile members being aggregated to produce some kind of inflorescence or flowers which may have been borne on ramifications of the stem. This seems to be the correct conclusion from the present evidence, and in accord with the view that foliage leaves were evolved from branch systems. There can be little doubt that the megaphyllous gymnosperms of Mesozoic, Tertiary and recent times belong to the second of the two lines suggested. The Triassic pteridosperms of the Corystospermaceæ and Peltaspermaceæ bore their seeds and pollen on slender systems of branches and not on leaves. The Caytoniales show the same feature, as do the modern Gnetales and Cycadales. In the latter group it has been the custom to describe the cones as bearing sporophylls, but this idea may require revision in the light of Professor Harris's demonstration that the Mesozoic *Beania* was a member of the Cycadales (1941). *Beania* resembles a seed-bearing cone of *Zamia*, and there is much to be said for the view that this represents the most primitive type of Cycad from which *Cycas* is a derivative.

The fertile branch systems of the Triassic pteridosperms, with their bracts and bracteoles, are like the dichasial inflorescences of some angiosperms ; they were probably produced from strong axes in a similar way. We know very little about the possible relations of the different forms of inflorescences in the flowering plants. The subject needs further study, but in a recent survey Rickett (1944) considered that the dichasium was probably the most primitive type; while Uittien (1928) some years ago found some correspondence between inflorescence types and leaf forms. Should my suggestions prove correct, it will follow that, from the evolutionary standpoint, we might continue to use the term sporophyll for branches of inflorescences in some flowering plants though not for stamens and carpels.

There is nothing in the fossil record which suggests the evolution of angiosperm flowers from a vegetative shoot bearing fertile leaves or branch systems which became condensed and reduced to give a flower, say, of the Magnolia type ; even the flower-like fertile structures of the Bennettitales give little real support to such a theory. But an increasing number of discoveries suggest the origin of flowers from terminal groups of sporangia which became surrounded by sterile perianth members that probably gave protection to the growing parts when young.

Important evidence on this aspect of plant history probably exists in the early Mesozoic rocks of the Southern Hemisphere. Some time ago Dr. A. L. Du Toit discovered in the Triassic beds of the Cape Province, two specimens which appear like inflorescences, probably branching in one plane, with the branches ending in small flowers. No published descriptions of these forms have yet been given and the state of preservation does not allow their exact determination as reproductive structures. They show, however, a whorl of delicate perianth segments on some of the branches and it is impossible to avoid describing these structures as flowers. From another locality Mr. Pyke found a specimen of somewhat different

form which also had flowers terminating slender branches. The floral organs show whorls of perianth segments, perhaps of two kinds, and within them, at the apex of the receptacle, lies a small group of elongated cylindrical structures with two projections at the upper end. These objects are remarkably like the bodies from the Permian of China described by Halle (1929 b) as the seeds of a pteridosperm and named *Nystroemia*. We cannot yet say whether they are seeds or carpels. No proper investigation of these forms can be made until a considerable number of additional specimens have been obtained, and it is hoped that efforts will be made to find such specimens in the near future. The field for palæobotanical research in Southern Africa and Australia is very great, and up to the present time very little collecting has been done. It may be found that there is good evidence of early angiospermous plants in this region, and if the flowering plants originated there in late Palæozoic or early Mesozoic times, the puzzling problem of their sudden appearance in the Northern Hemisphere at a later date may be solved.

Evolution of Carpels

It is not my intention to discuss to-day the problem of the origin of the carpel. The historical evidence on this matter shows that from a very early period the seeds of pteridosperms were surrounded by an envelope which enclosed them to a greater or less degree. It is perhaps unfortunate that these envelopes were called cupules, but this term has become well established and can be used in a biological sense. Similar cupular envelopes were present in the Mesozoic Corystospermaceæ, the Caytoniales and the earlier Bennettitales. They may therefore have also existed in the ancestors of the angiosperms. The Caytoniales show how such envelopes had become almost closed before pollination, though, as Professor Harris (1940) has demonstrated by his improved technique, not completely closed. I do not regard this group as the ancestors of the flowering plants although this view has been attributed to me ; but as was suggested in 1931, both Caytoniales and angiosperms may well be descended from common ancestors and the Caytonia ovary may furnish clues to the origin of the stigma and the closed carpel. Since my suggestions on this subject (1934) were published Professor Doyle (1946) has given us the results of his comparative studies on pollination and fertilisation in the conifers. He has shown that in some members of this group the place of germination of the pollen grains has probably become changed from the micropyle to a glandular surface some distance away. A similar change by which pollen grains came to rest and germinated at the mouth of a cupular envelope may have initiated the passage from gymnospermy to angiospermy. This suggestion can now be at least regarded as a biological possibility.

I have already spoken of the importance of thinking of possible evolutionary changes as events affecting plants as living organisms and not merely as changes in a morphological pattern. This especially applies to the evolution of the carpel. The fact that some carpels show the pattern of an infolded leaf is not a sufficient basis for a modern hypothesis without reference to the physiological and biological aspects of the problem. We have also to account for the prevalence of anatropous ovules, for the stigma and the transmitting tissue. Although the classical interpretation of the carpel has been so generally accepted this does not show that it is true, and we should be on our guard in presenting to our students a theory based on very unsubstantial foundations as a view which must be believed because it always has been believed. It may well prove that other hypotheses such as that suggested by Professor McLean Thompson (1934) will be found to fit the facts more nearly, but at the moment botanists have the choice between a hypothesis based on historical records of ovule protection extending over a wide range of forms and a long period of time, and hypotheses for which such evidence is lacking.

Further research on the structure of the gynœcium in living forms conducted from an inductive standpoint may go far towards clearing up the question of the origin of the carpel, but much remains to be done. We have no real reason to adopt a permanently agnostic outlook and to regard the problem as insoluble.

The Early Angiosperms

The fossil records of the Mesozoic rocks show that flowering plants of many different forms flourished in the Cretaceous period, and that by the end of this time they had become dominant in the world's floras. But as yet little attention has been paid to these early records as indicating the course of angiosperm evolution. On current theories most of the Cretaceous and Eocene types appeared to belong to highly advanced groups and no new hypothesis was suggested by their inspection. Sir Joseph Hooker (1854) cast doubts on the ability of geologists to recognise the genera and families to which fossil leaves belonged, and this view had

many adherents. To-day our knowledge is established on much firmer foundations, many fossil leaves, showing perfect preservation of their secondary veins, can be matched exactly with living forms, while additional characters may be provided by their epidermal structures. Seeds and fruits have been found which can be closely compared with recent forms, and a number of characteristic pollen grains have been identified. When different workers reach by independent studies the same conclusions about the genera and families represented in the fossil floras from different areas, we can scarcely maintain that they are all mistaken in all their determinations. Little doubt remains that representatives of many living families of flowering plants were flourishing some 60 or 90 million years ago and must therefore be regarded as relatively primitive types.

Interesting confirmation of this conclusion has recently come from the studies of the wood anatomists. Starting from the highly probable assumption that angiosperms have descended from gymnosperms. Frost, Kribs, Chalk (1937) and their fellow workers have established by mathematical reasoning the characters which distinguish the more primitive from the more advanced types of wood structure. The petrified woods from the British Lower Cretaceous described by Dr. Marie Stopes (1912) as the remains of the earliest known European angiosperms, show several of the characters believed by this reasoning to indicate primitive types, viz. scalariform pitting or perforation plates, fibre tracheides, and high medullary rays often clearly heterogeneous. Furthermore, 68 per cent. of the families recorded by Chalk as showing primitive wood have been recorded from the Cretaceous or Lower Tertiary rocks, from which it would appear that there is a correlation between age and wood structure. Mr. K. R. Sporne has studied this correlation by statistical methods and has shown it has a very high degree of probability.

Additional evidence as to the antiquity of the same types is furnished by a different consideration. It is well known that the seeds of the pteridosperms had a well-developed vascular system in their integuments, and that similar bundles are found in modern gymnospermous seeds, excluding most of the conifers. Some flowering plants also have integumentary vascular strands, but the majority have none. Here again we find that many of those families with this archaic feature are recorded from the London Clay or the older rocks, while others which have not yet been recognised in the fossil record have primitive wood.

It would now seem that we can distinguish, by the direct and indirect use of the fossil evidence, groups of angiosperms which may be regarded as relatively primitive without introducing any theoretical concepts of floral morphology. These groups show very varied characters, and if they sprang from common ancestors they must have begun to diverge very long ago. Although they show no apparent backward convergence towards any particular type, such as the catkin or the elongated flower of the Magnolias, we may be able to discover a number of features in which they are significantly different from a sample typical of modern flowering plants and so gain information about primitive angiosperms. This work has been well begun by Mr. Sporne, and appears to be a promising line of research. His preliminary results seem to confirm some of the indications furnished by the fossil record, such as the probability that the angiosperms descended from woody plants having unisexual flowers. It would seem from the record of the rocks that compound leaves preceded simple leaves, but most of the angiosperm families thought to be primitive on our new criteria have simple leaves. These simple leaves, however, usually have stipules and the stipules may perhaps represent the lateral leaflets of an original compound type. Engard (1944) found that the primordia of the stipules in *Rubus* were similar to those of the lateral leaflets, and this matter needs investigation.

The possibility that the trees of tropical regions may include some of the more primitive of the forms now living, increases the need for detailed studies on these types. As Mr. Corner (1946) has recently pointed out, our knowledge of many of these trees is based on fragmentary dried specimens in our herbaria and is most incomplete. I strongly support Corner's plea for more research on these plants, which is urgently needed since the forests of tropical regions are gradually disappearing and some forms may soon become extinct. Our present knowledge of the structure and reproduction of the flowering plants is mainly based on the investigation of the herbaceous forms of the Northern Hemisphere, and this may have led to ideas of limited significance.

When we survey the modern flowering plants with their thousands of distinct genera and hundreds of thousands of species, it seems very unlikely that they represent a group of relatively recent origin. The ideas relating to their possible structural history which have been suggested to-day imply that the changes in the form of the floral parts may have been far less drastic than has been previously supposed, and at the same time

we know that the changes which have taken place in certain families during the last 90 or 100 million years have been very small. It seems reasonable then to suggest that the group as a whole could scarcely have originated at a more recent period than the end of the Palæozoic epoch. An attempt has been made to show that forms of large-leaved seed plants existed during that time, which had features not far removed from the angiosperms. In the earlier part of Mesozoic time the flowering plants may have been a group already established on dry land in areas where the chances of preservation of its members were small. If this suggestion is true, it may be demonstrable by the discovery of angiosperm pollen grains in those wetter regions inhabited mainly by pteridophytes and gymnosperms of the older types. Dr. J. B. Simpson (1937) has already found such pollen in the Jurassic rocks and investigations should be actively pursued to determine if it can be found in other freshwater deposits of the Triassic and Jurassic periods.

I have long thought that our concepts of floral morphology and their bearing on evolutionary problems required a complete overhaul in the light of modern knowledge. The wonderful advances that have been made in plant physiology during the last fifty years have been largely due to the new concepts introduced by F. F. Blackman and his contemporaries, and the final rejection of deductive reasoning by which experimental results were interpreted as manifestations of unknown vital forces. More recently we have seen advances in genetics stimulated by cytological knowledge, and taxonomy clarified by a scrutiny of the philosophical basis of classification. I look forward to a similar renaissance in morphology. Doubtless some will disagree with the suggestions I have put forward as to the possible history of the flowering plants. But if the existing evidence is capable of a better inductive interpretation it will be welcomed by all. In my view there is abundant historical evidence that flowering plants have evolved from simpler types, and that more complete proof will be obtainable by continued investigation.

It was suggested that we should consider at this meeting of the British Association the application of war-time discoveries to the peaceful development of scientific knowledge, and this idea has been constantly in my mind. As an Officer who has served in the Air Photographic Intelligence branch of the services in two world wars I have been impressed by one lesson we should learn from both of them. The lesson is that wishful thinking and a subjective appreciation of a military situation invariably leads to failure, while success only comes after a thorough collection and examination of all the relevant facts and an appreciation of the situation based on these facts. We should not be meeting here to-day had our leaders been satisfied with the idea so prevalent from 1939 to 1941 that we really knew all that was necessary about the strength and resources of the enemy, and consequently that day-to-day search for fresh information was unnecessary. This information was very often most unpalatable, especially when it disclosed the failure of our plans and operations, but it provided a true picture of what had to be met. Are we already beginning to neglect this lesson, and to regard the world and the events which are taking place around us subjectively, or through a mist of personal bias or political prejudice? Scientists should continually remind their fellow citizens that great differences may exist between things as they are and the same things as we should like them to be. In our botanical problems, as in the wider field of national and international affairs, real progress can only come by the steady employment of scientific modes of thought. Information must be collected from all sources and objectively analysed; from this a true appreciation of the present situation can be based, and plans prepared for future action.

One of the original purposes of this Association was to ensure a better appreciation of the importance of Natural Science. To-day the results of scientific investigation are widely appreciated, but the scientific method and the mode of thought by which results have been obtained are less widely understood. It is therefore our duty to see that our own work and teaching is free from reproach, and to advocate the habit of scientific thought in all the affairs of life.

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SECTION L.—EDUCATION

THE EVOLUTION OF SECONDARY EDUCATION IN ENGLAND

ADDRESS BY

Miss LYNDA GRIER

PRESIDENT OF THE SECTION

The country in which I have the honour to read this paper has thought about education much and consistently for generations. My address is concerned with educational progress in a country which has thought about education little and spasmodically. Yet I hope it may not be thought unnatural, now that England has decided to give secondary education to all her children, to devote the presidential address of this section on the first occasion on which it meets after so revolutionary a decision to a review of some of the major causes leading to it. They have made it slow and peculiar, and they are likely to be of importance in determining its outcome. Among them I propose to consider the dominance of the classical tradition in English education, and the effect of the growth of democracy on that tradition, and to touch on the influence of modern subjects and of the new humanism contained in the approach to scientific and even, or perhaps especially, to technical studies.

The classical tradition in English education is no longer as dominant as it was, though it is still powerful in some of the greatest of our public schools, and though it still colours the curriculum of the grammar schools, more especially those for boys. I believe we have to look further back than the oncoming of science teaching, and the beginning of the secondary education of girls for the gradual breakdown of the dominance of classical teaching. In mediæval times and somewhat later it was not only true that learning was comprised in the classical tongues, that scholarship meant classical scholarship, but classical scholarship was useful. It was the language of the Church till Henry VIII meddled with the Church. It was the language of charters and legal documents. It was, indeed till the end of the seventeenth century, the language of diplomacy. And the Tudors liked their courtiers to be not only courtly but learned. So those who were ambitious for their sons were eager for them to be good classical scholars. That way advancement lay. High office in Church and State, standing in the learned professions might be hoped for by those who had classical lore. 'Grammar' meant Latin grammar in the schools founded in those days, and it is remarkable how many such schools were founded. Latin was the esperanto of the world, and the world was fortunate in having an esperanto which had a great literature, and was an introduction to great history and great thought.

Roger Ascham, Queen Elizabeth's famous tutor, gives in the very title of the *Scholemaster*, written in 1571, a good illustration of the esteem in which Latin was held: 'The Scholemaster; or plaine and perfite way of teaching Children, to understand, write, and speake the Latin Tonge, but especially purposed for the private bringing up of Youth in Jentlemen's and Noblemen's Houses, and commodious also for all such as have forgot the Latin Tonge, and would, by themselves, without a scholemaster, in short tyme, and with small paines, recover a sufficient Habilitie, to understand, write, and speake Latin'. In the text he further states that: 'all men covet to have their children speak Latin'. He asseverates that he has earnest respect to three special points, 'trothe of religion, honestie in living, right order in learninge', but seems to think that all will be acquired by learning the Latin tongue.

He pours contempt on other studies: 'Some wittes, moderate enough by nature, be many times marde by over much studie and use of some sciences, namelie musicke, arithmeticke and geometrie. These sciences, as they sharpen mens wittes over much, so they change mens manners over sore, if they be not moderately mingled, and wisely applied to some good use of life. Marke all

mathematical heades, which be only and wholly bent to those sciences, how solitary they be themselves, how unfit to live with others, and how unapt to serve in the world. This is not onelie knowen now by common experience, but uttered long before by wise mens judgement and sentence. Galene sayeth, much musicke marreth mens manners : and Plato hath a notable place of the same thing in his Bookes De Repub : . . .' It will be observed that his objection to other studies is largely that they are useless. Truly the wheel has come full circle. It will also be noted how much stress he places on the ability to speak Latin.

The use of the English Bible, and the English Prayer Book, did not for a time affect the practical value of the classics. They were still essential to the learned professions, to diplomacy, still an advantage to those who coveted high place at court. It should be noted, however, that the utilitarian nature of their studies was no narrow one ; not only because of the rich store of scholarship opened to them, but because of the number of professions from which they might take their choice once they had mastered the classics. Their subject did not make them the servant of any one profession, rather it gave them the mastery of choice among many. But the fact that the classics gave great education and opened many avenues did not interfere with the fact that they were useful, so long as Latin was a living language and not a dead one. Greek indeed had long been dead in the sense in which I am speaking, though the interest in the Bible awakened by its use in the common tongue revived its study for some time after the Reformation, but it always ranked second to Latin as an instrument of instruction in the schools, grammar being Latin grammar, not Greek.

As the Latin language became dead, no longer of use for the learned professions, or for diplomacy, or for life at court where in Stuart times wit and elegance were of more account than learning and where in Hanoverian times little account was taken of any of these things, it may be a matter of surprise that French did not supersede Latin for teaching in schools. But it did not. Latin had become too deeply embedded in the educational ideas of the times, as the means of giving young Englishmen the mental training they required for being gentlemen. There was unease in the matter. Bacon, in 1605, complained that the classics opened the door only to the few learned professions. Locke, writing at the end of the seventeenth century, though looking upon Latin ' as absolutely necessary to a gentleman ' is clearly troubled in his mind by the education which ' fits us for the University rather than for the world ', and goes on to recommend that he would like a gentleman to learn ' a trade, a manual trade ; nay, two or three, but one more particularly ; ' and he notes ' the busy inclination of children, being always to be directed to something that may be useful to them.'

In his anxiety to put right what he takes to be wrong with English education, Locke did not fully grasp the nettle. As we have seen, he was under the bondage of the classics to the extent of thinking that a man could hardly be a gentleman unless he knew Latin, but, being convinced that other studies were necessary, instead of suggesting their inclusion in the school curriculum he proposed that they should be taught by tutors who thought Latin and language ' the least part of education ', and even went so far as to say that mothers who knew no Latin themselves could teach it well to their children by means of a Latin Bible.

During the period in which Latin became a dead language, the schools and universities, which continued to base their studies on Latin, themselves decayed. It is noticeable that as Latin ceased to be of direct use, the education which it filled fell into contempt. No new colleges were founded at Oxford or Cambridge between 1612 and 1800.[1] Few new schools were founded. Of the 180 boys' schools in England now belonging to the Headmasters' Conference, 85 were founded before the end of Elizabeth's reign, of which 32 had been founded before the dissolution of the monasteries, and the remaining 53 between 1536 and 1603. Many others of equal standing must have perished altogether. After 1620, when the impetus given during Tudor times had died down, less than a dozen of such schools were founded until the revival of the nineteenth century. It may be suggested that there were other reasons for these figures than the declining value of Latin as a preparation for ' the world.' Times were disturbed after the reign of Elizabeth ; yet they were perhaps not more disturbed in the eighteenth century than in the sixteenth. And it may be argued that there were enough schools already founded to meet the needs of the population : an argument that is hardly ever to be admitted in education which of all things should grow by that it feeds on. Moreover, it does not explain the fact that the numbers both in schools and universities declined during the seventeenth and eighteenth centuries, and that revival of numbers and of standards came with the admission of subjects which were more allied to life as men were living it and not as they had lived it in other lands and at other times.

[1] Wadham, Oxford, 1612 ; Downing, Cambridge, 1800.

The author of the introduction to the Spens report wrote that we should remember ' that subjects were not invented for scholastic purposes, but are the tools and instruments which the human race has crystallized out of its experience in order to understand the world in which it lives.' Greek and Latin alone could no longer do that. Always they will make a contribution to such understanding and to the understanding of our own language, for the greatest masters of English are generally classical scholars. But other subjects are essential, and it is perhaps largely to slowness in admitting that fact that the slow growth of secondary education in England is due.

But something more is also due to it ; namely the idea, by no means yet eradicated from among us, that if education is to be liberal, if it is to be education at all, it must be useless, must have no economic value, must not minister to ambition, or serve mercenary purposes. Everyone admits that there is something fine in this idea. We all bow before the disinterestedness of the true scholar. Yet we have to admit that even the truest scholar, must, unless he has private means, live by his scholarship, and the schoolmaster lives by his teaching. That they do not as a rule live at all fatly by either, that they might have done far better for themselves had they used their abilities in another walk of life is also admitted and wins homage as proving their true love of their subject and of their work, since, though they live by it, they could live better by something else.

But the world does not consist solely, or indeed largely, of scholars—and still less of classical scholars. It was bad for scholarship and education in general that they should be confined to one set of subjects in a world which as time went on had great thought, great literature, great history, in lands other than those of Greece and Rome. It was bad for the schools and universities that they should so long ignore the importance of the new scientific learning which grew up outside their ken. And it was bad for the country as a whole that those who had no interest in scholarship as such should remain uneducated because the school education was so remote from the world in which they were to play their part. Schools and universities fell into contempt, and any scheme for secondary education was set back by decades if not by centuries. Unfortunately the contempt of those who thought nothing of the men who could afford an education which equipped them for little but elegant speech and writing was matched, perhaps more than matched, by the contempt of those who thought that there was something superior in being able to afford not to earn a living and therefore that all education should assume that you need not do so. This perverse conception of education has coloured English education for generations. As we have seen, it arose during the time when classics were no longer necessary for the learned professions. But it dominated English thought to a mischievous extent, and perpetuated snobbish ideas in education.

The history of snobbishness in English education is a fascinating study, and one that would repay serious research by some qualified educational historian. From very early days the idea predominated that education was for the few, not for the many ; it is true that Sir Thomas More, writing in the first half of the sixteenth century, conceived of a population which took its whole pleasure in reading and in philosophical discourse, while only those ' are excused from labour so that they can give themselves wholly to their studies ' who ' discover from their childhood an extraordinary capacity and disposition for letters.' But More was several centuries ahead of his time in his ideas ; moreover, he assumed a nation which used slave labour, though to a modified extent.

For the most part education had a certain aristocratic flavour ; though the early founders of grammar schools were often more liberal in their ideas than those who followed them. Again and again the grammar schools were founded for the children of the rich and poor alike, and there was general insistence that the schools should be free so that none should be excluded by poverty. The Schools Enquiry Commission (1868) quoted the words of Cranmer in this connection : ' Utterly to exclude the ploughman's son, and the poor man's son from the benefit of learning . . . is as much as to say that Almighty God should not be at liberty to bestow his great Gifts of grace upon any person, nor nowhere else but as we and other men shall appoint them to be employed, according to our fancy, and not according to his holy will and pleasure, who giveth his gifts both of learning and other perfections in all sciences unto all kinds and states of people indifferently. . . . Therefore if the gentleman's son to be apt to learning, let him be admitted ; if not apt let the poor man's child, that is apt, enter his room.' The words might almost have been written four centuries later, and the action that was taken by pious founders with these ideas in view were much like those of the English Minister of Education three years ago. But there was this difference : Cranmer and those who shared his views, and they seem to have been many, took it for granted that if the ploughman and the poor man's sons received a grammar school education they would enter one of the

learned professions. They did not expect them to adopt the avocations of their fathers. The ploughman was not expected to follow the plough with a Greek or Latin text in his hand. Nor was the classical education given thought suitable for the growing class of traders and merchants. Locke, for instance, jibed at those whose sons are going into trade or industry for having them taught anything so useless as the classics. Therefore, although there seems to have been at that early stage none of the horror of gentlefolk in later centuries at the idea of their children associating with the children of those of different parentage, there was a distinct flavour of intellectual aristocracy about the whole idea, since the education given would lift the children from being manual workers to being something different. For this the classical tradition was from the first responsible; since the study of the classics, even when it led to many professions, even when Latin was a live language, was of no service to the boy or girl who did not wish to join a learned profession.

The breakdown of the classical tradition has been slow. But the Universities of Oxford and Cambridge (there were, of course, no others in England) began to acknowledge the value of other studies when they introduced mathematics into their curriculum at the beginning of the nineteenth century, Cambridge insisting that all students should study mathematics before they could take a degree in classics. There had been schools founded during the seventeenth and eighteenth centuries to teach the art of navigation and some mathematics and science in an age in which all these things were rapidly developing; but they affected the grammar schools little. For the most part, with notable exceptions such as that of Christ's Hospital, these continued in their old ways with their former curriculum, fortified by the habits of the ancient public schools and the universities. But in the long run changing times were too strong for even the most conservative schools. And at least one university has recently decided not to insist on Latin test for all students reading arts. How far the swing of the pendulum will go remains to be seen. But all who have to do with secondary education know how deeply embedded is the notion that grammar schools are superior to other secondary schools, and that no school has the right to call itself a grammar school unless it teaches Latin to all its more intelligent pupils. The ordinary parent wants his son to go to the 'Grammar School' because of the prestige which attaches to the name, and not specially because he wants his boy to learn Latin. The schoolmasters continue to teach Latin, some because their schools have always done so, some because they want as many as possible of their boys to go to the university, and some because they genuinely believe that it is essential to anything that can be called education.

But when all is said and done, it is probable that in future more and not fewer children will study classics and with advantage. With the increased numbers in secondary schools, more children will have the chance to discover their true interest in the subject. And as all learning is placed at the door of all children, all subjects are likely to have more devotees.

In speaking of the classics I have already touched on the liberal ideas of Cranmer and of many of the founders of grammar schools in their desire to throw them open to all children who were likely to profit from the kind of teaching given, and have shown that, though free for the most part from the snobbishness of later days in not hesitating to mix all children of whatever parentage and upbringing in the same schools, they were expecting the children of manual workers who went to such schools to follow some occupation other than that of their parents. (A few schools were founded for the sons of gentlemen; but this was rare and generally speaking late, after the end of Tudor times.) But always for the manual worker, including the highly skilled manual worker, grammar school education was not thought suitable. For him the system of apprenticeship provided a satisfactory education, and many were the pious foundations for the apprenticeship of the young. For the needs of those who were going to be merchants, and industrialists and farmers on a large scale or small there was no provision. There were some among those interested in education who thought that the education of a gentleman would be improved by his learning a trade; many felt something was wrong if the leaders of the country were helpless with their hands; Sir T. More wanted all to learn some trade, and so did Locke, noting that: 'The great men among the antients understood very well how to reconcile manual labour with affairs of State, and thought it no lessening of their dignity, to make one the recreation of the other' . . . 'Gideon amongst the Jews was taken from threshing, as well as Cincinnatus among the Romans from the plough, to command the armies of their countries against their enemies; and it is plain that their dexterous handling of the flail, or the plough, and being good workmen with these tools, did not hinder their skill in arms, nor make them less able in the arts of war or government. They were great captains and statesmen, as well as husbandmen.'

But this insistence on manual work was for the sake of the highly educated, not for the sake of the work or the general run of workers. The idea was selective, and for the most part remained selective for centuries.

The great Moravian educationist, Comenius, two centuries ahead of his time, had quite other notions. According to him all children were to be educated, all given a chance for higher education. The education was to be graded according to age, and all children were to pass into grammar schools at the age of twelve. Not till then was Latin to be taught. It was to be replaced by an immense number of other subjects. At one time it seemed likely that Comenius and his ideas might find more acceptance in England than elsewhere ; for in 1641 he was invited to England by a friend of Milton's, with the idea that he might be head of a college for the promotion of the physical sciences on lines suggested by Bacon in the *New Atlantis*. But the scheme ended with the outbreak of the Puritan revolution, and the clock was put back for nearly three centuries. Milton, though Comenius had been brought over by his friend Hartlib, had no real democratic sense and gave as his ideal for secondary education the establishment of a highly selective seminary for highly intelligent young people, who were to work unbelievably hard. I think we owe something to this selective idea. It had much to do with the remarkable number of endowments for scholarships in England. This was, of course, not at all the same thing as giving all children an opportunity of learning, but it was something to give many an opportunity of mounting the educational ladder. It became increasingly possible for able children, whether rich or poor, to get a good education. But clearly under this practice, some able children were not discovered, and some of those who were discovered were unable as time went on to obtain admission to the secondary schools because the places were filled by the children of parents who were able and willing to pay for them.

In the long run a truly democratic community, such as Comenius thought of, is bound to ask why all children should not be given the same opportunities as wealthy ones. *The Great Didactic* of Comenius might almost have been written for us to-day. ' If any ask, "what will be the result if artisans, rustics, porters, and even woman become lettered ? " I answer, " If this universal instruction of youth be brought about by the proper means, none of these will lack the material for thinking, choosing, following, and doing good things. All will know how the actions and endeavours of life should be regulated, within what limits we should progress, and how each man can protect his own position." ' In general terms he says, ' not the children of the rich or of the powerful only, but of all alike, boys and girls, rich and poor, in all cities and towns, villages and hamlets, should be sent to school. In the first place, all who have been born to man's estate have been born with the same end in view, namely that they may be men, that is rational creatures, the lords of other creatures, and the image of their Creator. All, therefore, must be brought on to a point at which being properly imbued with wisdom, virtue and piety, that may usefully employ the present life and be prepared for that which is to come. God Himself has frequently asserted that with him, there is no respect of persons, so that if, while we admit some to the culture of the intellect, we exclude the others, we commit an injury not only against those who share the same nature as ourselves, but against God Himself who wishes to be acknowledged, to be loved, and to be praised by all upon whom he has impressed his image. In this respect the fervour of men will increase in proportion to the flame of knowledge that has been kindled. For our love is in direct ratio to our knowledge.' Among those who Comenius wished to include in the comprehensive scheme of education were the stupid, partly because we were not infallible in deciding who were the stupid ; a humility which might well be shared by others to-day.

Now, centuries after Comenius wrote, we are beginning to carry out some of his ideas. In particular we have come to his conclusion that education should be graded according to age, not according to social class. I am inclined to think that one of the strongest though not the most noticed influence in this direction has been the gradual raising of the school age, and the consequent overlap between the work in what have been called elementary schools, under an elementary authority, and the early stages of schools which have been recognised as secondary. It was not until 1899 that all children were obliged to remain at school till they were twelve, the age be it noted at which Comenius thought they should pass to Grammar schools. And there it remained till the passing of the Fisher Act, of 1918, which made it compulsory for all children to remain at school full time until the end of the term at which they reached the age of fourteen.

That Act made the overlap between the age of children in the two types of school, elementary and secondary, even more marked than before, and it is not surprising that, hard on the heels of the Act, there came a demand from the Education Advisory Committee of the Labour Party, in a book edited by R. H. Tawney, for *Secondary Education for*

All. The situation had become somewhat ridiculous, as none could contend, given the history of some of England's greatest self-made men, that brains or high standards were the monopoly of any class, or of the children of parents with a minimum income level.

That children of the same age should need different cubic space, different equipment, differently prepared and differently paid teachers, in schools supported wholly or in part by the State, simply because the parents of some could afford to pay fees while others could not, was not a thing that could be tolerated for long. As long as it could be supposed that on account of age some children needed a more expensive education than others, the differences could be maintained with some logic, if not with justification, but the moment that the overlap became universal things changed, and men's minds were attuned to the new idea, which as we have seen in reality was very old, that education should be arranged in stages according to age. Of course the overlap did not begin with the passing of the 1918 Act. There had been plenty of overlap before, with the higher grade elementary schools of the end of the nineteenth century, whose support from the rates was declared illegal by the Cockerton judgment, by the fact that the majority of children did not become part-time workers and therefore continued to receive full-time education till fourteen, and by the development of the central schools which gave a more practical type of education to children who remained at school after the school age and yet were under the elementary authority. The change did not therefore come suddenly, but the general application of the Act which compelled *all* children to receive education beyond anything that could be called elementary made the overlap a glaring anomaly.

I have deliberately spoken of the anomaly created by the overlap in schools maintained wholly or in part by the State. Into this category the problem of those schools not so maintained does not enter. And the overlap has forced the hand of the Government with regard to free secondary education, for you cannot well say to parents whose children have hitherto been educated freely up to fourteen that they must in future pay for their education because the schools which they are henceforward to attend will be called secondary. And to draw a fee-paying line between some schools and others would make for worse anomalies than before, and worse snobbishness. Again, there is nothing new about the idea of free secondary education. We have seen that many of the founders of early grammar schools stipulated that no fees should be charged in their schools. The stipulation soon became a dead letter for two reasons—one, that the endowments rapidly became inadequate when prices rose, and two, that there was a strong conviction that parents valued the education more if they had to pay something towards it. The Schools Enquiry Commission, which was much concerned with the matter of endowments, laid considerable stress on both these points. The first led quickly to the charging of extras, and it was naturally held better to charge a uniform low fee to all children, than to charge very high fees to some under the heading of extras. If one or the other was necessary because of rising costs, the uniform fee was held to be more in accordance with the wishes of the founders than the discrimination demanded by the other method.

How far there is truth in the idea that people despise things for which they do not pay directly (indirectly, all pay through rates and taxes), it is perhaps idle to inquire now that the decision has been taken not to demand payment. The view varies from one person and, perhaps, from one part of the country to another. That there is something in it, is unfortunately proved by the persistence with which people have sent their children to really bad private schools where they pay higher fees than they would in good schools where there are either no fees or low ones. That persistence may be partly accounted for by the desire of parents to keep their children away from contact with others whose parents cannot afford the fees, but in general it is, I think, due to the idea that they are getting something better for their children by the price they pay for it. They have been too ignorant to know that, often, the inadequate fees they pay ensured worse premises, less qualified teachers, and a less good organisation than could be secured under a Local Education Authority. With inspection we hope that this will be a thing of the past.

The movement for the higher education of women and girls is a natural part of the movement towards democracy, though not all democrats recognised it as such. It appears that many of the early grammar schools were founded for both sexes, and gradually came for the most part to be used only for boys. There are various estimates of the extent to which they were in this matter diverted from their proper use, but there is no doubt that in some cases diversion took place. Always there were advocates of the higher education of women, Sir Thomas More being among the most doughty, as well as one of the earliest in England. He was followed by others, but the leaders of Protestant revolution took even less interest in the higher

education of girls than in that of boys. Individual efforts indeed there were, but no general movement. As we have seen, Comenius was anxious for the general education of members of both sexes. It is amusing to compare his words first written in Czech in 1632 with those of the Rev. Sydney Smith in the *Edinburgh Review* in 1809. Comenius wrote: 'Nor can any sufficient reason be given why the weaker sex should be altogether excluded from the pursuit of knowledge (whether Latin or in their mother tongue). They also are formed in the image of God, and share in his grace and in the kingdom of the world to come. They are endowed with equal sharpness of mind and capacity for knowledge (often with more than the opposite sex) and they are able to attain to the highest positions since they have often been called by God Himself to rule over nations, to give sound advice to kings and princes, to the study of medicine and of other things which benefit the human race, even to the office of prophecying and inveighing against priests and bishops. Why, therefore, should we admit them to the alphabet, and afterwards drive them away from books? Do we fear their folly? The more we occupy their thoughts, so much the less will the folly that arises from emptiness of mind find a place.'

Sydney Smith wrote: 'That there is a difference in the understandings of the men and women we every day meet with, everybody we suppose must perceive; but there is none surely which may not be accounted for by the difference of circumstances in which they have been placed, without referring to any conjectural differences of original conformation of mind. . . . If the objections to the better education of women could be overruled, one of the greatest advantages that would ensue would be the extinction of innumerable follies.'

Smith admitted that women were better educated than they had been a century earlier, for the age of blue-stockings had begun. The stirring of the intellectual waters which both accompanied and followed the Industrial Revolution had affected women as well as men, and had affected the attitude of, at any rate, some men to women and their education. I do not want to dwell on the oft-told tale of the efforts for the higher education of women, but only to point out that the awakening came at the same time as that for the newer education of men, of the education, that is, which was to come with the development of the new humanism, the admission of the sciences to the curriculum of the ancient universities, the impetus to the foundation of new private or 'proprietary' schools, for girls as well as boys, so that at last when the State took on the provision of secondary schools there was no question but that they should be established for both sexes. And we must also note in passing that this has had a profound effect, as has often been pointed out, on the curricula of all schools, for though girls' schools have been accused of copying too closely the ways of boys' schools, they have in fact never had the same curricula, or the same enslavement to the classical languages. One other point. The girls' high schools made a very special contribution to democratic education; for parents have been far slower to send their daughters than their sons to boarding schools, partly because girls' boarding schools lacked the tradition of some of the ancient boarding schools for boys; partly because they were more reluctant to let daughters out of their sight; and partly because if they could only afford boarding school fees for some of their children they thought it more important to spend the money on their sons than on their daughters.

Consequently girls, far more often than boys, mixed at their schools with children from every kind of home, to the great advantage of all.

Something has already been said of the growth of science, of the fact that much of the effeteness of the grammar schools and the universities during the seventeenth and eighteenth centuries was due to their neglect of living and growing subjects and to their devotion to dead languages. Education did not revive till the doors of schools and universities were opened to new learning, and it was admitted that it was worthy of the highest gifts of scholars. Once again learning began to explain the world in which men and women were to live and work. Much has been written and spoken about this, and I do not propose to dwell on it. But something must be added about the growth of interest in technical education, though the last occupant of this chair was able to deal with the matter fully and with authority.

Long after the battle for science was won in all but the most conservative educational camps, that for technical education lagged behind. It was possible for scholars of the ancient type to admit to their fraternity those whom they called 'pure' scientists, men who did not think of making their living by their subject except through holding research posts, or teaching it, and did not do anything so low as to suggest that their pupils might earn their living by the kind of work for which their scientific studies specially fitted them.

There was a long struggle at the end of the nineteenth century to have technical education acknowledged as secondary and put on the same basis as other secondary education.

But the struggle was only successful in name. In spite of the need for England to do something on the same lines as other countries in the matter, it was still assumed that the ablest children would go to grammar schools and the second layer to technical ones. Grade of ability rather than type of ability remained the test by which it was decided what children received what kind of education. In a sense it is to the credit of the grammar schools they should have gained so high a place in public esteem. But it has been bad for technical education, unfair to the children noticed by Locke as having that busy inclination to be doing something that would be useful to them. Perhaps particularly unfair in a country whose people have been accused by Senor de Madariaga of thinking best and most efficiently when they act. Surely the most unsuitable nation to be dominated by a type of education which takes a pride in having no direct bearing on the business of living. We all know the people who not only claim to, but do, clean saucepans, cook meals, and garden magnificently, because they have read Greats. But they have the not entirely common ability to transfer the teaching they have had to activities as well as to passivities, and to use well-trained minds on everything. But not all have the power to get their minds well trained that way, and not all of those who have possess the power of transfer.

Technical education was not, of course, neglected before the nineteenth century, but it was in the hands of the master craftsmen. There were innumerable endowments for apprenticeship, some of which are now an embarrassment to those responsible for them. Like other endowments they often became inadequate. But the general decay of apprenticeship was due rather to the change in industrial methods brought out by the Industrial Revolution than to any other cause. It has required a complete change of focus to make us believe that the work done by the employer in the old days should be done by the State now. Slowly we are coming to it. For the work is not on the same lines. It is more general, or should be so if it is to be education and not merely training. It tends to make the worker more independent of the particular employer rather than dependent on him. Ideally it should be what a knowledge of Latin was to those who wished to enter one of the learned professions in earlier days, an introduction to a number of occupations, the slave of none. Here we must qualify, for industries are so vast and complex that a technical training, e.g. in engineering, may not be any special qualification for work outside engineering, but it should enable its pupils to specialise later in a variety of posts in the engineering field. The same should be true of agriculture and a variety of other industries for which the State can organise education. And the schools which give technical education of this nature should as well, I would gladly say as much as the grammar schools, lead on to universities. But there is yet much misunderstanding, and indeed animosity to overcome, much absurdity to be avoided. There are, on the one hand, people who will not believe a directly useful education can educate, and they are often backed by the people who suspect technical education of being just a tool of the employer who may want to enrich himself by getting well-trained workers at the taxpayers' expense (it may be noted that he has long been able to get educated workers at the taxpayers' expense). On the other hand, there are others who take too narrow a view of education and think that teaching anyone anything that is useful to him in his job is worthy of being called education. We go from one extreme to the other, and indeed the steps are often short from a wide technical education to a narrow technical training such as Abraham Flexnar has ridiculed in his book on the Universities of England, Germany and America. I think it would be possible to take the general line that anything which was useful for only one narrow range of occupations was unsuitable for the university, but that at the secondary school stage subjects of direct utilitarian value can be fitted into a truly educational curriculum and give it interest and purpose.

Before ending this discussion on the evolution of Secondary Schools it is necessary to say something more specific of the schools which have played so large a part in it, namely the private or proprietary or independent schools. Clearly since there were no State secondary schools till this century, and there was a good deal of advanced education, private effort and endowment must have done much. And the very lateness of our national effort meant that those bodies, often of a religious character, which had established schools were more 'dug in' than in other countries which had recognised their obligations earlier. It is probably true, therefore, that England had both the best and the worst schools in the world.

For good or ill then, England is faced with an immense variety of schools, of school governments, of teaching methods. Since there is a vast variety of children, a variety of the ways in which they are catered for appears all to the good. So it is, if the variety of catering fits the variety of children. But there was little in the past to ensure that. For day school children the type or types of provision might or might not fit the children

of the neighbourhood. For the children who were to be boarders there was more chance, especially when the parents took, as they frequently did, the most intense interest in the selection of the right kind of school for their children. Sometimes they were too much swayed by sentiment and by a desire to see their boys at the school they had been at themselves, even if the boys were of a very different type from themselves. Sometimes they were guided by motives more or less snobbish, in thinking that at a certain school their children would meet boys of the 'right kind.' But whenever educational motives prevailed, the boys at boarding schools stood a better chance of going to the school for which they were fitted than the boys at day schools, except in great cities where there was a wide choice. A little country town might well have only one school which catered for boys above the elementary school age. Such a school might serve a wide area, and it might be good or bad. It might be good for some boys, very bad for others. The variety, or lack of it in the curriculum would depend on the headmaster, and perhaps on the governors. There was nothing in these schools to impose a minimum standard, just as there was nothing to impose a maximum one, and an independent school could, through small classes, highly qualified teachers and so forth, offer a very fine education if by high fees, or large endowments, or both, they were able to pay for these things. This was more often the case with boarding schools than with day schools. The best of the so-called public schools owe much to their wealth, whether it comes from the present affluence of parents or from the generosity of past benefactors.

What I have said, I have deliberately said of boys' schools rather than of girls', which do not seem to me to have come into their own, or to have had the same standards as the best of the boys' schools. The best have perhaps been those which most closely copied the best of the boys' schools ; but that has not made for originality of treatment, and I think that there is still much to be done in the way of experiment with girls' schools. I have already spoken of the effects of the more modern curricula in girls' schools on those of the country as a whole. And this we owe to the private schools. Some of the worst schools have undoubtedly, however, been those for girls. Largely again because of the parents' lesser interest in preparing their daughters for any paid work, assuming that they would marry, and therefore not have to provide themselves with an income. At one end of the scale some of these schools will now be swept away because of their squalor and inefficiency. At the other end I am not quite so sure that we shall so easily be rid of the most futile schools to which some wealthy parents send their daughters. Much has been said about the amount that some parents are prepared to spend to get their sons educated, but very little about the money they spend to prevent their daughters from being educated. Once more the idea that daughters will not have to earn their own living is to blame. It has even put a premium on ignorance, since it is held in some circles that intelligent and well-educated women stand less chance of marriage than the ill- or under-educated ones. It is to be hoped that the inspectors who deal with schools will be capable of dealing with these as they deserve and will not be deceived by the charming manners and deportment of the young women they find in them, or dazzled by the affluence and the high position of their parents. They form a small section of the community, but an influential one.

Having so far looked back, may I spend the last few minutes in looking forward, not in a spirit of prophecy but of hope ? It is true that we have lost the natural esperanto of the Middle Ages and the Tudor world. I think we lost it effectively as soon as Latin ceased to be a living language. Any substitute must be based on, and not a basis of, modern languages ; it cannot, moreover, be the introduction to great literature, great history or great thought. So much with the march of time we have lost. But I think we have gained something even in the loss, since such a language was neessarily the monopoly of a certain class or group of people, and we no longer can tolerate an international language which is known only to some. Interpretation is better than that. I think that at this moment it is proving better than that. In a democratic world we want every statesman to be able to express himself in his own natural tongue, that he may be understood by his own people, while the people of other lands also hear what he has said in their own language. It is perhaps unfortunate that in a world in which physical contacts between nations are swifter than ever before, nationalism is expressing itself so vehemently in linguistic differences and perpetuating the tower of babel, regardless of the literary or philosophical value of the babelistic tongues. But there England at any rate is not poor, and with the coming of general secondary education it is likely that a large proportion of her sons and daughters will have at least one language other than their own at their command.

If we have lost something, I repeat that I think we have gained more, infinitely more. We have dropped, or are dropping the illiberal idea that a liberal education means

a useless one, just as we have dropped the idea that there is something to be admired in the man or woman, perhaps especially the woman, who does nothing useful.

More and more as the school age rises, and the content of education widens, we feel after not so much a course, as courses, of general education which will give to every kind of child with every kind of gift and background a good entry into, and a good choice of occupation in the modern world. And it is on the note of variety that I would end. It is our great heritage from the past. We have every sort of approach to secondary education. We have every type of it. And I hope we shall evolve many more types, and so continue to respect the individuality of our children and of the contribution which each may make to the common good. It is not in uniformity that we get unity. What unity is there in a blank sheet of paper compared with that of a picture in which there is endless variety, and from which the omission of a single detail would spoil the picture, if it be a good one? Or, if you prefer a living simile, what unity is there in acres and acres of cabbages, of wheat or of greensward compared with the unity of a garden to which every generation makes its contribution of thought and culture, and in which every tree however great and every blossom however small receives the individual care and thought that leads to its fullest development. We have come in England disgracefully late to anything that can be called a system of secondary education. But our very lateness may help us to preserve what has been most valuable in our lack of system, namely freedom and variety; things which have surely helped England in promoting gifts of inventiveness, and of leadership, which will, we trust, be given yet more scope in the wider conception which we now have of what secondary education may do and be.

SECTION M.—AGRICULTURE

SOILS AND HEALTH

ADDRESS BY

W. G. OGG, M.A., Ph.D.

PRESIDENT OF THE SECTION

In recent years much has been spoken and written about soils in relation to the health of plants, animals and human beings, and, because of the importance and interest of the subject and in view of some of the assertions that have been made, it is perhaps opportune to review the present state of our knowledge. At the outset it is necessary to recognise that there is an immense variety of soil types which differ from each other in physical properties, chemical composition and various other ways. The differences are due to the rocks or other parent materials from which the soils have been derived, to the climatic and topographical conditions under which they have been formed, to the vegetation and other living organisms associated with their formation, and to their age. The soil, in fact, may be described as a synthesis of geology, climate, vegetation, topography and time.

If certain chemical elements are absent from a parent rock, they will naturally be absent from the soil derived from it unless they happen to be carried in from outside sources—for instance, by water, wind or ice ; but even if present in the rock they are not necessarily present in the surface soil for, under some conditions, they may be carried away in the soil drainage water or moved to another part of the soil profile during the weathering processes. On the other hand, there can be a concentration of certain elements in the course of soil formation, and this is seen, for example, in the " alkali " soil types.

There is also the question of availability to plants of the materials present in soils, and obviously availability is as important as the total amount present. All this has a bearing on plant nutrition and on the kind and amount of vegetation which the different soils can support. Different types of plants differ greatly in the amounts of the essential elements which they require and, under natural conditions, the available nutrient status is one of the main factors determining the type of vegetation. The nutrient conditions are not always ideal even for the natural vegetation, and the conditions in agricultural land are frequently even less satisfactory, for crops are often grown on soils which, without treatment, are far from suited to their needs.

One of the most important and interesting advances made in recent years in the study of soil fertility is the recognition of the part played by what are often termed the trace elements. It has, of course, long been recognised that, for normal healthy growth, plants require other elements in addition to nitrogen, potassium, phosphorus and calcium, but until comparatively recently it was assumed that these four were the only ones necessary to add as manures, and that the others were present in sufficient amount and in available form. For most soils that is the case, but it has now been shown that deficiencies in other elements are much more common than it was at one time supposed and that they give rise to deficiency diseases not only in plants but in the animals which consume them.

Besides the four elements just mentioned, plants require magnesium, sulphur and iron in relatively large amounts, and there are other elements which have been shown to produce beneficial effects on the growth of certain plants but which do not appear to be essential. Sodium, for instance, has a definite value in the manuring of sugar beet, and for this crop is a plant food.

In addition to these major plant foods, traces of certain other elements are essential. Up to the present, this group has been shown to consist of boron, manganese, copper, zinc and molybdenum. Other elements, for instance, arsenic, lead and nickel, are toxic even in low concentrations. Of the trace elements required by plants, manganese, copper, zinc and molybdenum appear to be necessary also for animals, and cobalt and iodine, which do not seem necessary for plants, are nevertheless required by animals.

The quantities of the trace elements required by plants are very small, usually only a few parts per million or less, but they must be present in the soil in available forms. Manganese deficiency, for instance, may occur in soils with a high content of total manganese. Another point to be noted is that too much may be as detrimental as too little, and it is easy to give an overdose. Two elements, molybdenum and selenium, can be taken up by plants, without ill effect, in amounts which are highly toxic to animals.

We do not know very much about how the trace elements act—what rôle they play in plant and animal nutrition—but possibly they are catalysts. At any rate, their discovery has cleared up the problems of many plant and animal diseases.

As has already been noted, deficiencies may occur though large reserves of nutrients are present in the soil in unavailable forms, and the availability may be affected by many different factors such as climatic conditions, soil reaction, conditions of aeration, organic matter and microbiological population. The relative proportions of the various elements also affect their availability and excess of one element may inhibit the uptake of another by plants. High potassium, for instance, increases and high nitrogen decreases magnesium deficiency.

The Occurrence of Mineral Deficiencies and Excesses

It is obviously of very great importance to agriculture to have as much information as possible about the natural distribution and availability of the elements concerned with the nutrition and health of plants and animals. Much of our knowledge on this subject is due to the geochemical studies of the late Professor V. M. Goldschmidt of Oslo, who was a scientific guest at Rothamsted and the Macaulay Institute for three years during the war. Developments in methods of quantitative spectrography, both X-ray and optical, in Goldschmidt's and other laboratories, have been of great value in obtaining the necessary analytical data, and his investigations have revolutionised our knowledge of the distribution of the trace elements in the earth's crust. Advances in the knowledge of crystal structures have permitted the determination of the atomic and ionic radii of the majority of the elements and so enabled the prediction of their occurrence to be made. From thermo-chemical considerations, a more fundamental explanation of the well-known order of segregation of the elements in the earth has been provided whilst consideration of ionic size has shown in which minerals any given element might be found. The entry of ions or atoms into the three-dimensional network of crystals is determined by inter-atomic bonding forces. Thus iron and magnesium freely replace each other in olivine, but magnesium, being slightly smaller, enters the crystal first. In micas, lithium can replace magnesium only after most of the latter has entered the crystallising mineral because lithium, although of the same size as magnesium, has the smaller charge. It is now possible to classify the elements on the basis of their ionic and atomic radii into a number of groups within which isomorphous replacement is possible and so obtain a series of host minerals in which certain elements are likely to occur.

When the minerals of igneous rocks become weathered in the course of sediment and soil formation, other principles affect the distribution of the elements and it has been shown that the ionic potential $\left(\frac{\text{ionic charge}}{\text{ionic radius}}\right)$ which measures the electric field strength at the surface of the ion, provides a clue to the problems of the destination of the ions in the sedimentary cycle. Thus elements of low ionic potential tend to form cations in solution (e.g. Na, K, etc.), those of very high ionic potential form the central element of oxyacid anions, whilst those of intermediate ionic potential tend to remain as oxides or hydroxides (e.g. Fe, Ti, Al, etc.). The state of oxidation of the elements is, of course, of great importance, particularly in relation to their availability to plants. Goldschmidt's researches included studies of the trace elements in coal ash, forest litter and sea water. Important geochemical work in relation to agriculture has also been carried out in recent years by R. L. Mitchell and his colleagues at the Macaulay Institute.

Let us consider very briefly the geochemistry of three of these trace elements—boron, iodine and cobalt, as examples.

According to Goldschmidt, much of the boron passed from the primordial atmosphere to sea water, but the present boron content of of the sea is only the balance of a much higher content, large amounts having been accumulated in marine sediments. Marine mudstones and shales contain on an average ten to fifty times as much boron as eruptive rocks and, where they occur, are the source of a great deal of the boron in soils. In the processes of rock metamorphism boron is immobilised as the resistant mineral tourmaline which appears to be of little value to plants. In soils rich in lime the boron may be immobilised through the formation of borates of calcium. It would appear, therefore, that in the course of geological history an increasing part of the boron is being locked up in

insoluble minerals. In regions which have comparatively recently emerged above sea level, the percentage of available boron is usually adequate for plant growth.

Iodine, like boron, has been concentrated to a considerable extent in sea water and is carried through the air to soils. The concentration in soils appears to depend largely on their distance from the sea and the direction of prevailing winds. Soils formed in relatively recent times from rocks poor in iodine tend to be deficient in it, especially if they are far from the sea; but soils as a rule contain much more iodine than the rocks from which they were derived.

Cobalt is associated with the ferro-magnesian minerals in magmatic rocks owing to the similarity of the ionic radii of cobalt, magnesium and iron. The ionic radius of cobalt is slightly smaller than that of ferrous iron, but distinctly greater than that of magnesium, so that concentration of cobalt is to be expected in the mixed crystals of the silicates of iron and magnesium in basic intermediate igneous rocks and in soils derived from such rocks. From sands and porous sandstones cobalt is often removed by leaching, and the content in limestones is often low.

Most of these geochemical studies deal with the parent materials of soils rather than with the soils themselves, and much research has still to be done on the effects of the pedological or soil-forming processes on the distribution of the nutrient elements.

Soils in Relation to Plant and Animal Diseases

Major nutrients

Although the needs of agricultural and horticultural crops for nitrogen, potassium, phosphorus and calcium have long been recognised and the principles of manuring and liming are so well established, deficiencies in these elements are very common. They are indicated by symptoms in the foliage, by reduced yields and by the chemical composition. In many cases they are responsible for animal diseases. Cows receiving insufficient lime and phosphate in their diet react by robbing their own bones, and sheep living on a low-calcium diet associated with lack of sunshine or vitamin D may suffer from ill health and bone deformity. A low ratio of calcium to phosphorus has been shown to cause a bone disease in horses and low serum calcium is often associated with low blood magnesium in cases of grass tetany. The injection of calcium and magnesium salts has proved beneficial in the early stages of grass tetany, but there is as yet no definite evidence that the disease is a result of deficiencies of these elements in the diet, though the possibility of this cannot be excluded.

Turning again to crops, magnesium deficiency, which is probably more common than is generally realised, especially on light acid soils, affects fruit, particularly apples, and various agricultural crops. It is easy to remedy by applying magnesian limestone as a liming material.

Iron deficiency is rare in agricultural crops, but chlorosis, due to iron deficiency, associated with soils of high lime content, is common in fruit plantations. It can often be cured by growing a grass sward over the roots of fruit trees, but the reason for this is not understood. There is probably enough iron in practically all soils and the problem appears to be one of availability or of mobility of the iron in the plant tissues.

The remaining major element, sulphur, does not seem to present deficiency problems in this country but, in some parts of the world, tea suffers from a condition known as ' tea yellows ' due to sulphur deficiency.

Trace elements

Boron.—More than twenty physiological diseases of cultivated plants have already been attributed to boron deficiency. In this country, the most important is probably ' heart rot ' or ' crown rot ' of sugar beet and mangold. Other diseases are ' raan ' or ' brown heart ' of swedes and turnips,' internal cork ' of apples and ' topsickness ' of tobacco. The deficiency is most prevalent on light acid soils and the tendency for the disease to develop is increased by liming and by hot dry weather. Boron is also of importance in the nodule formation of leguminous plants, being required for the proper formation of the vascular strands of the nodule. The deficiency is readily corrected by applying borax to the soil before sowing the seed or by spraying the crop.

Manganese.—Most soils contain sufficient manganese, but under certain conditions it is unavailable to plants, and deficiency diseases are fairly prevalent in several parts of Britain, for instance, in the Fens, Romney Marsh, and parts of Yorkshire. In oats it gives rise to ' grey speck,' in peas to ' marsh spot ' and in sugar beet to ' speckled yellows.' The deficiency is associated particularly with calcareous peats and other soils rich in humus with a high lime status. It also occurs on certain calcareous silts and silt clays with impeded drainage or a high water table. The problems of manganese availability are complex and have not yet been fully elucidated. Recent work has shown that deficiencies may be due to an upset of the relative rates of manganese oxidation and reduction, and the

oxidation-reduction processes are at least partly biological. In soils of neutral or alkaline reaction, oxidation of manganous manganese is favoured and the soil manganese is therefore present mainly in the form of higher oxides. It is claimed that deficiency is unlikely to occur provided sufficient of the higher oxides is present in a reactive or readily reducible form. The part played by organic matter is at present under investigation. It appears that manganous manganese forms complexes with soil organic matter. A study of the conditions of formation or breakdown of such complexes in soil may throw light on the association of manganese deficiency with soils of high organic-matter content.

On the other hand, excess of soluble manganese is highly toxic to plants and may be the explanation of some of the ill effects of high soil acidity.

Manganese also affects animal health, and a deficiency of it is said to bring about a disease of young chickens known as ' perosis ' or ' hock disease.' The symptoms are deformity of the leg and wing bones which are shorter than normal. Whether the action is direct or indirect, the addition of manganese to the diet was found to cure the disease. An excess of manganese, on the other hand, has been suspected to be the cause of ' forage anæmia,' an infectious anæmia affecting horses grazing on certain natural forest pastures in Scandinavia and Finland. The evidence for this, however, is very incomplete.

Copper and zinc.—Both normally occur in soils in very small amounts, 1 to 50 p.p.m. in the case of zinc and rather more in the case of copper. Zinc deficiency causes several diseases of fruit trees in the United States and various other countries, and is said to be responsible for low yields of cereals in some parts of Australia and for a disease known as ' white bud ' of maize. It appears to occur over a wide range of soil conditions, and it has been suggested that micro-organisms may, at any rate in some cases, render the zinc unavailable.

Lack of copper brings about diseases of fruit trees in various parts of the world, notably ' exanthema ' or ' die-back.' It also affects farm and vegetable crops and on recently reclaimed moorland gives rise to ' yellow tip ' or ' reclamation disease,' which can be controlled by the application of copper sulphate to the soil. Copper deficiency appears to be particularly prevalent in moorland peats and acid sandy soils and gravels, but it also occurs in calcareous sands in Australia. As in the case of zinc, soil organisms may be concerned in the unavailability.

Several animal diseases are attributed to copper deficiency. In Holland a disease of cattle known as ' licking sickness ' occurs in areas where there is a copper deficiency in the soil and where ' reclamation disease ' affects cereals and other crops. The symptoms of licking sickness are anæmia, loss of appetite and a general deterioration of the condition of the animal. Treatment with copper was found to effect a cure. Another disease in Holland attributed to copper deficiency occurs on the sandy soil reclaimed from the Zuider Zee. It is known as ' scouring disease ' and affects cattle and goats. The copper content of the blood, liver, milk and hair of affected animals is low, and cures have been effected by feeding copper and cobalt and sometimes copper alone. There is doubt, however, whether this is a case of a straight copper deficiency.

No fewer than four diseases in Australia have been attributed to lack of copper. ' Enzootic ataxia ' which affects unweaned lambs can be prevented by giving copper sulphate to the gestating ewes and checked by dosing the lambs already affected. ' Sudden death ' or ' falling disease ' affects dairy cattle, and the symptoms are loss of condition, anæmia, and depraved appetite. It occurs in copper-deficient areas and is prevented by feeding copper salts. A disease known locally as ' rickets ' or ' wobbles ' and a condition known as ' stringy wool ' also occur in the copper-deficient regions in Australia. The former affects foals and calves and is characterised by malnutrition and abnormalities in structure and posture of the limbs. The latter affects sheep, their wool becoming straight, limp and glassy. There are indications that both diseases respond to copper treatment.

Two other diseases, ' swayback ' in lambs and ' scouring disease ' on what is known locally as ' teart ' land, respond to treatment with copper, but there is no evidence that they are due to copper deficiencies in soil or herbage. The symptoms of swayback are a swaying gait, particularly of the hindquarters, and sometimes blindness. Feeding copper to pregnant ewes is said to be effective in preventing swayback, and it has been suggested that the disease may be due to high lead or zinc in the pasture interfering with the absorption of copper from the alimentary tract. Scouring disease is due to molybdenum excess.

Molybdenum.—Traces of molybdenum appear to be essential for nitrogen fixation by Azotobacter and also for symbiotic nitrogen fixation in Leguminosæ. Typical nodules seem to form in molybdenum-deficient soils but they have a very low nitrogen-fixing capacity, and pasture improvement in many

areas of South Australia would appear to depend on the stimulation of clover by the addition of molybdenum. It may be involved in the metabolism of higher plants as well as in the processes of nitrogen fixation, but the evidence is not very conclusive.

On the other hand, excess of molybdenum is harmful. There are pastures in certain parts of Somerset, Warwickshire and Gloucestershire, known as 'teart' pastures, which have an unusually high content of molybdenum, 30–40 p.p.m. compared with 4-5 p.p.m. in normal pasture. On these a scouring disease occurs affecting cattle and, to a less extent, sheep, when they are turned out to grass. Hay and dead winter herbage do not produce the disease as readily as green grass, and this may be because the molybdenum, which has been shown recently to be the cause of the disease, is less soluble in the dried material. The 'teart' pastures are found on certain soils of neutral or alkaline reaction with a high content of molybdenum that are derived from the Lower Lias formation. If the surface soil is acid, the disease does not occur even though the molybdenum content is fairly high. The disease can be prevented or cured by dosing the animals with copper sulphate, but no explanation of its action has yet been given.

Selenium. Another excess which can give rise to a disease is that of selenium. In certain regions of North America and here and there in other parts of the world it has been shown to cause what is known as 'alkali disease,' affecting horses, cattle, pigs and poultry. In the United States, at any rate, the disease appears to be confined to arid and semi-arid regions. The symptoms include anæmia, emaciation, depraved appetite, loss of hair from mane and tail and lesions in various internal organs. 'Blind staggers,' which is regarded as an acute form, is characterised by almost complete blindness and varying degrees of paralysis.

There are some curious features of the disease. It would appear that only a limited range of plants including a vetch, *Astragalus bisulcatus*, can take up selenium in harmful amounts from the soil minerals, but that when these plants are ploughed in, the selenium becomes available to any subsequent crop. In the absence of these converter plants, selenium can be present in the soil without detriment to animals. Seleniferous soils capable of producing toxic vegetation would appear to be confined to areas of fairly low rainfall. It has been suggested that this is the disease to which Marco Polo referred in his account of his travels in China.

Cobalt and iodine.—Although these two elements have not been shown to be essential plant nutrients they appear to be necessary for animals. Deficiency in cobalt causes animal diseases which, in different countries, have gone under different names such as 'enzootic marasmus' in Australia, 'bush sickness' and 'Morton Mains' disease in New Zealand, 'pine' in Scotland and 'salt sick' in Florida. These maladies, which are either allied or identical, affect sheep and young cattle grazing in certain areas. At first it was thought they could be cured by giving large doses of iron compounds, but later it was found that cobalt, present in traces in the crude iron salts, was the curative agent. Treatment can be given in the form of salt licks or drenches—but it is more convenient to treat the soil. The amount required is infinitesimally small, two pounds of a cobalt salt, mixed for convenience with a fertiliser and applied to an acre of land, being sufficient to cure or prevent the disease. In Florida and certain parts of Australia the cobalt deficiency appears to be associated with a deficiency of copper, and treatment with salts of both elements is necessary. Pining is liable to occur if the cobalt content of the herbage is less than about five parts per hundred million. Different species of plants take up very different amounts of cobalt from the soil; for instance, rye grass and red clover take up about three times as much as cocksfoot. In soils with low cobalt content the species in the herbage may, therefore, be the deciding factor in the occurrence of the disease.

Iodine deficiency in the soil appears to be associated in some way with the incidence of goitre in man and in farm livestock. Attempts to correlate the incidence of goitre with the iodine content of the food have not been entirely satisfactory, and, although there is no doubt about the beneficial effect of iodine in the treatment of goitre, iodine deficiency may not by the only factor responsible for the disease.

There is still much to be learned about these mineral deficiencies and excesses, and doubtless further diseases will be found to be caused by them. They do not seem, in most cases, to affect the health of human beings, because human food, as a rule, is drawn from such a wide area that a deficiency in one article of diet would probably be made good in another drawn from a different region.

The Contention that Fertilisers are Detrimental to Health

Let us now turn from fact to fancy. Particularly in recent years, virulent and unprovoked attacks have been made on the practice of using fertilisers. It is claimed that they poison the soil and are injurious to the health of plants, animals and human

beings. Most of those who hold these beliefs are quite unscientific in their outlook, but they often use or misuse scientific terms, and some of them carry out what they allege to be scientific experiments and quote scientific work which appears to fit their own views.

There are various degrees of belief. Some regard even lime with suspicion, and rightly so if they object to the chemical process of converting a carbonate into an oxide in lime-burning. Some would allow ground mineral phosphate but would object to potash salts, although both are natural deposits. Even basic slag is acceptable in certain quarters, but superphosphate is anathema, probably because sulphuric acid is used in its manufacture and also because of the erroneous belief that superphosphate renders the soil acid. The most intense dislike, however, is reserved as a rule for sulphate of ammonia, possibly because at one time it was all made from gas works liquor, but it may be considered less objectionable now that so much of it is made from the nitrogen of the air.

The opposition is not confined to fertilisers. All chemical aids to agriculture and horticulture are condemned and every trick is used to try to disparage the offending substances. Insecticides and fungicides become ' poison sprays ' and fertilisers are ' artificials ' or ' chemicals.' Those holding the most extreme views not only reject fertilisers and the so-called ' poison sprays ' but engage in rituals recalling the magical practices of the alchemists or the antics of the witch doctors.

Some base their beliefs on curious anthroposophic philosophies ; others simply dislike chemicals and do not appear to realise that whether nitrogen, for example, is applied to the soil as dung or as a fertiliser such as sulphate of ammonia, it is changed by micro-organisms in the soil to the same or similar chemical compounds before being taken up by plants. There is usually a harking back to the ' good old days ' when everything was more natural and, therefore, better, but the ills now attributed to these new-fangled substances existed long before fertilisers were discovered and are rife in regions where they have never been used. The opponents of fertilisers hold their beliefs with religious fervour, and those who disagree with their assertions are often accused of having unworthy motives and being in the clutches of the fertiliser interests, or have attributed to them views which they do not in fact hold, for instance, that they neglect organic manures and discourage their use. An attempt has been made to create a controversy where in fact there is none, for every scientific agriculturist realises the value of organic manures and advocates their careful conservation and fullest possible use. It is not a case of choosing between them and fertilisers. Both have their uses and they should be regarded as complementary.

In the days of subsistence farming when the food was consumed largely in the countryside in which it was grown, the losses of plant nutrients were much less than they are at the present time. We are unlikely, however, to go back willingly to the sanitary contrivances of the Middle Ages, and during the past few years a great deal of attention has been given to the utilisation of sewage sludge as a manure. Unfortunately, only a limited amount of the plant food is recovered in the sludge, and a drawback to its widespread use is the cost of transport. Sludges vary a great deal in composition, and even the best of those so far examined are inferior to good farmyard manure. There has been much talk of composts, and these are excellent as far as they go, but on a clean well-managed farm, run on ordinary lines, the amount which could be prepared from the weeds and crop residues would be quite trivial. True, it would be possible to organise the production of crops for composting, but the land and labour required for this would very greatly increase the cost of our food supply and reduce the area of land available for food crops.

Much use is made of such expressions as ' living soil ' as if this were some new discovery and biological soil studies are extolled whilst those connected with chemistry are disparaged, but the soil's population of micro-organisms was not discovered by the anthroposophists or any of those holding similar views. The pioneer work on the subject was done at Rothamsted between 1877 and 1890 by Robert Warington, and at the present time the department of Microbiology is one of the largest in that experiment station. Chemistry has contributed much to our knowledge of soils, but for many years physicists, microbiologists, botanists, zoologists, biochemists and geologists have also taken part in soil studies and in the building up of the new science of pedology.

Alleged harmful effects on the soil

The charge is often made that those who use fertilisers are exploiting the fertility of their land, using up its organic matter and leaving it in an impoverished condition. The reverse is, in fact, the case. Fertilisers properly used build up fertility, making good what is taken out in crops or by stock and what is lost through drainage. By enabling larger crops to be grown, fertilisers increase the amount of material which can be converted into farmyard manure, and the greater amount of roots left as residues by the larger crops also increases the organic

matter in the soil. One undoubted advantage that organic manures have over fertilisers is that they are almost foolproof. You can hardly go wrong with them. But the fact that it requires intelligence to derive full advantage from fertilisers should not be accepted by farmers in this or any other country as a sufficient reason for not using them. Under most systems of agriculture to-day the amount of farmyard manure produced is quite inadequate, and it must also be borne in mind that when a soil deficiency occurs, the crops and, in turn, the farmyard manure or composts tend to show the same deficiencies. It is recognised that the fertilisers must be used properly and in the correct form and amount to suit the needs of the soil and crops to be grown. The fact that sulphate of ammonia increases the rate of removal of lime from the soil is recognised. In time this leads to acidity, but it is readily corrected by liming.

Soil erosion is sometimes attributed to the use of fertilisers, and though only indirectly connected with health deserves mention. It certainly occurs in some regions where fertilisers are used extensively, for example, in the Cotton Belt of America, but in the notorious 'Dust Bowl' the average annual consumption of fertilisers just before the war was less than two pounds per acre of crop. In both places the erosion has been due to the system of farming and not to the fertilisers. Fertilisers may be employed in bad farming systems, but it is unfair to condemn their use when in fact they have been misused.

In any event, the remedy for many of these bad farming systems will be found in resting the land under leys or cover crops. To establish these crops successfully it will often be necessary to introduce fertilisers as the United States is now doing so enthusiastically and efficiently in its soil conservation schemes.

The claim is often made that fertilisers have an adverse effect on the soil's population of microscopic living things—the bacteria, actinomycetes, protozoa, soil fungi and other organisms. Careful tests, however, made on the classical plots at Rothamsted have given us evidence that the application of inorganic fertilisers, even for many successive years, has not had any deleterious effect on the soil micro-population. The conditions in the soil needed by the farmer are those most suited to the growth of his crop. The crop and the soil micro-organisms alike depend on suitable and generally similar degrees of soil aeration, moisture and reaction and on an adequate supply of inorganic nutrients. An improvement in physical conditions or in mineral nutrient supply is thus beneficial alike to the crop and the micro-population of the soil. But the micro-population differs from the crop in that it ultimately depends on the energy material supplied by soil organic matter, the quantity of which usually acts as a limiting factor. So that we can, of course, increase the soil organisms by adding easily decomposable organic matter to the soil. But a mere increase in numbers is not necessarily beneficial to the crop. Indeed, if there is too much organic matter rich in carbohydrates, the increase in micro-organisms may make so heavy a demand on plant nutrients such as nitrogen, as to compete with, and even temporarily to starve, the crop. On the other hand, the well-recognised improvement in soil structure often produced by organic matter seems largely to depend on microbial activity.

It is also contended that fertilisers reduce the earthworm population of the soil, but this is not borne out by recent work at Rothamsted. The highest earthworm populations are on areas where there is abundance of suitable organic matter on which they feed, but the application of fertilisers, even in abnormally heavy and frequent dressings, has no adverse effect provided the soil has not been allowed to become too acid —a condition which can be remedied by liming. Plots which have received heavy dressings of sulphate of ammonia have been compared with unmanured plots and the former contain as many earthworms as the latter, but the weight of worms on the nitrogenous plots is much greater due presumably to the greater amount of vegetation (roots, stubble, etc.) produced as a result of the extra nitrogen. The earthworm story will be dealt with at greater length by A. C. Evans at another session of these meetings.

Alleged harmful effects on plants and animals

It has been alleged that fertilisers increase the liability of crops to insect, fungus and virus attacks, but, again, there is no sound evidence to support this. At Rothamsted, although slight differences have been found in the level of infestation of meadow foxtail and wheat by the foxtail and wheat blossom midges, these differences can be accounted for by the extra number of grass and wheat ears on the plots. Thus the nitrogenous plots on Broadbalk have more gall midges on them but also more ears of wheat. There is no evidence of a greater percentage attack.

Conversely, unbalanced manuring can lead to an actual increase in the incidence of attack. In the case of barley, lack of superphosphate retards the growth of the plant, and consequently the infestation of barley by the gout fly is increased.

Experiments on the effect of manuring on

aphid infestation of potato and sugar-beet crops and the consequent spread of virus diseases have shown the spread to be greater with organic manures than with fertilisers.

Much work has also been done on the effects of manuring on the incidence of fungal diseases. The results show that the effects depend on the particular disease. For example, the incidence of eye-spot of wheat and Verticillium wilt is increased with nitrogenous manuring, whereas the incidence of others, such as take-all of cereals, is reduced. It does not appear to make the slightest difference, however, whether organic manures or inorganic fertilisers are used.

Another assertion is that fertilisers have a detrimental effect on the composition and quality of agricultural produce. The composition of crops can certainly be influenced by a number of factors, including manuring, but there is no conclusive evidence to show that organic manures have any special effect, beneficial or otherwise, compared with fertilisers. Whether fertilisers or organic manures or both are used there should be a proper balance of nutrients to supply the needs of the crop. Certain substances which stimulate root development in plant cuttings have been separated from organic materials such as urine and also prepared synthetically, and attempts have been made to show that organic manures owe some special virtues to such substances. This is possible, but so far there is no evidence that these growth substances increase crop yields or have any effect on composition or quality. Up to the present this class of substance has found its agricultural use not as a plant food but as a weed-killer.

Most of the work on composition of produce has dealt with dry matter, proteins, the major mineral constituents and a few vitamins. The data on the effect of manuring on vitamins are still rather scanty and a few experiments are often quoted which indicate that crops grown with farmyard manure have a higher vitamin content than those grown with fertilisers. There are, however, more experiments in which it has been found that there is no difference. For instance, tests carried out some years ago, at the Dunn Nutritional Laboratories in Cambridge, showed that the vitamin-B_1 potency of wheat grown at Rothamsted on plots which had received heavy annual dressings of fertilisers for over ninety years was at least equal to that from the plot which had received fourteen tons of farmyard manure annually over the same period. A similar result was obtained for barley from the classical Hoos field, and potatoes grown in a normal rotation which were tested for vitamin C showed no difference whether grown with dung or sulphate of ammonia.

A recent American experiment has compared the nutritional value of grass grown in a fertile soil well supplied with organic matter with that from a large-scale artificial water-culture medium, free from organic matter. The conclusion reached was that in both cases the animals made good growth and gave evidence of nutritional well-being and that there was no evidence that the plants grown in the inorganic medium were deficient in any dietary essentials.

The introduction of fertilisers about a century ago has led to an enormous increase in food production throughout the world, and during the past quarter of a century great advances have been made in our knowledge of the effects of mineral deficiencies and excesses on plant and animal health. Where the deficiences or excesses are pronounced, disease symptoms often develop, and the long catalogue of nutritional diseases which has been given is an indication of the importance of the subject. In less acute cases there may be no actual symptoms of disease, but crop yield and composition are affected and animals do not thrive as well as they should. The sub-clinical cases are no doubt far more numerous than the obvious cases of disease, and the loss to agriculture from them must be very great.

Although most of the diseases just described are due to trace-element deficiencies or excesses, we must bear in mind that food supplies and health are affected to a far greater extent by the major plant foods, and deficiencies of these are much more widespread. There are huge tracts of land in various parts of Australia, Africa and India, for instance, where, on account of acute phosphate deficiency, only the most meagre crops can be grown and the provision of greatly increased supplies of synthetic nitrogen and other fertilisers is one of the most obvious means of combating the present widespread famine. Fifty thousand tons of additional nitrogen properly distributed would give an extra million tons of wheat or rice. For the season 1946–47 the Combined Food Board was faced with reasoned demands for 3·3 million tons of nitrogen which was twice the previous year's consumption and fifty per cent. above pre-war production.

Probably more can be done for the improvement of health in the world to-day by providing ample supplies of food than in any other way, and the propagation of unfounded beliefs about the harmful effects of fertilisers is detrimental to the interests of the whole community.

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